**Bond University**

**DOCTORAL THESIS**

# Quantification of the physical demands and perceived wellness associated with practice and competition in NCAA division I college football players.

Wellman, Aaron

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# Quantification of the Physical Demands and Perceived Wellness Associated with Practice and Competition in NCAA Division I College Football Players


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A thesis submitted in fulfillment of the requirements of the degree of Doctor of Philosophy

Supervisors: Dr. Chris McLellan and Dr. Vernon Coffey

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## Declaration of Originality

I declare that the work in this confirmation document has not previously been submitted in whole or in part, for a degree or diploma to any university. To my knowledge, this thesis contains no material previously published or written by another person except where due reference is made within the thesis itself.

Signed: ______________________

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## Preface

American football is a field-based team sport, characterised by high-intensity collisions, and repeated high-intensity movements, requiring high levels of muscular strength, power, speed and agility (197). Competitive games are intermittent in nature, involving high-intensity bouts of exercise following brief periods of recovery (111). Further, the intensity of impact forces sustained during collisions that frequently occur in American football contribute an additional stress and trauma (216) which can alter athlete performance (105), contributing to post-match fatigue and prolonged recovery reported in similar collision-based team-sports (158). During the in-season phase of competition, players competing in National Collegiate Athletic Association (NCAA) division I college football participate in twelve regular season games on a weekly basis. Throughout the total duration of pre-season preparation and in-season competitive periods, players are required to participate in football specific training that includes repeated exposure to high-intensity exercise and high-impact forces, which have been associated with fatigue in collision sport athletes (157, 158, 237). Managing the volume and intensity of exercise workloads throughout the course of weekly training and competitions is a critical component of physical preparation in NCAA division I football players, in attempts to reduce the risk of acute and residual fatigue, and optimise preparedness for on-field performance.

The development of global positioning system (GPS) technology with integrated tri-axial accelerometers (IA) have allowed the physiological demands of training and match-play in team contact sport to be quantified (9, 242). Movement profiles, which include measurements of total distances, velocities of movement, and the number, distance, and durations of sprint, acceleration and deceleration efforts can be quantified utilising GPS (49, 50, 240). Integrated tri-axial accelerometers, which assess the frequency and magnitude of full-body acceleration ($m \cdot s^{-2}$) in three dimensions, namely, anterior-posterior, mediolateral, and vertical (143), offer a valid tool for detecting the frequency and magnitude of collisions associated with training and competition in team contact sport (73).

The impetus for the present body of work arose from several years of observing high pre-season training loads in NCAA division I football teams, particularly in the first week of pre-season training camp, and the residual fatigue associated with these loads, which often lingered into week one of the competitive season. The lack of information pertaining to the practice and competitive demands of NCAA division I football players is indisputable in any systematic review of the literature. Moreover, no study had quantified the positional movement demands of practice or competition, let alone the individual perceived wellness profiles associated with these demands.

The present body of work was undertaken to establish the physical movement demands associated with pre-season training camp practice, in-season practice sessions, and competitive games, along with the resulting perceptions of wellness associated with these demands. A novel series of studies was designed to provide a framework from which sport coaches and performance staff may utilize the findings as a means to improve practice planning and recovery strategies to optimize competitive performance and mitigate the deleterious effects of fatigue in NCAA division I football players.

**Navigation of the Thesis**

This thesis comprises five studies presented as five individual chapters. At the time of submission, three of the five studies have been published, while the remaining two have been accepted for publication. All papers are presented in the format accepted for publication and include an introduction, review of the literature, methods, results, and discussion section.

There are eight chapters which make up the present thesis. Chapter 1 provides an introduction of the purpose, significance of the research, presents the hypothesis associated with each study and outlines the research questions. Chapter 2 provides an overview of the literature with specific reference to the physiological and movement demands of contact team sport, including NCAA division I football, Rugby League, and Australian rules football. The reader is introduced to Global Positioning System (GPS) and IA (Integrated Accelerometry) technology for movement analysis in team sport, in addition to the validity and reliable of portable GPS technology. Chapter 2 also contains a review of the utilization of self-report measures, in the form of questionnaires, to evaluate the perceived wellness associated with training and competition in athletes.

Chapter 3 is Study 1, and has been published as:

**Wellman, A.W.**, S.C. Coad, G.C. Goulet, and C.P. McLellan. Quantification of competitive game demands of NCAA division I college football players using global positioning systems. Journal of Strength and Conditioning Research 30: 11-19, 2016.

Chapter 4 is Study 2, and has been published as:

**Wellman, A.W.**, S.C. Coad, G.C. Goulet, and C.P. McLellan. Quantification of accelerometer derived impacts associated with competitive games in NCAA division I college football players. Journal of Strength and Conditioning Research 31: 330-338, 2017.

Chapter 5 is Study 3, and has been published as:

**Wellman, A.W.**, S.C. Coad, P.J. Flynn, M. Climstein, and C.P. McLellan. Movement demands and perceived wellness associated with pre-season training camp in NCAA division I college football players. Journal of Strength and Conditioning Research, 31: 2704–2718, 2017.

Chapter 6 is Study 4, and has been accepted for publication as:

**Wellman, A.W.**, S.C. Coad, P.J. Flynn, T.K. Siam, and C.P. McLellan. A comparison of pre-season and in-season practice and game loads in NCAA division I football players. Journal of Strength and Conditioning Research, In Press, 2017.

Chapter 7 is Study 5, and has been accepted for publication as:

**Wellman, A.W.**, S.C. Coad, P.J. Flynn, T.K. Siam, and C.P. McLellan. Perceived wellness associated with practice and competition in NCAA division I football players. Journal of Strength and Conditioning Research, In Press, 2017.

The Journal of Strength and Conditioning Research was selected as the journal to receive the results of studies 1-5. It was reasoned that if the applied programming of practice and training protocols was to be improved, the results of these studies should be presented in a journal widely read by strength and conditioning coaches and sport performance practitioners. As such, the Journal of Strength and Conditioning was the journal of choice.

In addition to the studies listed in chapters 3-7, the research conducted in completion of the present thesis also contributed to the preparation of the following poster presentation:

**Wellman, AW**, Coad, SC, Goulet, GC, and McLellan, CP. Quantification of competitive game demands of NCAA division I college football players using global positioning systems. Presented at the 2015 National Strength and Conditioning Association national conference, July 8-11, Orlando, FL.

Chapter 8 contains the overall discussion and conclusions, a summary of the findings of the studies, and recommendations for future research, which may increase our understanding of the physiological movement demands and perceived wellness associated with participation in NCAA division I football. The results of the present body of work will aid coaches and performance staff in the programming of practice loads and recovery protocols, which optimize game-day performance and mitigate the deleterious effects of fatigue that may accompany participation in NCAA division I football.

## Acknowledgements

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I would also like to extend a genuine “thank you” to a number of colleagues including Sam Coad, Ty Siam, Patrick Flynn, Grant Goulet, and Mike Climstein.

## Abstract

The primary aim of this thesis was to quantify the positional movement demands of pre-season and in-season practice and competition in NCAA division I football players. A secondary aim of this thesis was to examine the subsequent perceived wellness, utilizing a modified questionnaire, associated with pre-season training camp and competition throughout an NCAA division I football season.

**Chapter 3 (Study 1 – Paper 1)**

The aim of the present study was to examine the competitive physiological movement demands of NCAA division I college football players using portable global positioning system (GPS) technology during games, and to examine positional groups within offensive and defensive teams, to determine if a player's physiological requirements during games are influenced by playing position. Thirty-three National Collegiate Athletic Association (NCAA) Division I Football Bowl Subdivision football players were monitored using GPS receivers with integrated accelerometers (GPSports, Canberra, Australia) during 12 regular season games throughout the 2014 season. Individual datasets (n = 295) from players were divided into offensive and defensive teams, and subsequent position groups. Movement profile characteristics including total, low-, moderate-, high-intensity and sprint running distances (m), sprint counts, and acceleration and deceleration efforts, were assessed during games. A one-way ANOVA and post-hoc Bonferroni statistical analyses were used to determine differences in movement profiles between position groups within offensive and defensive teams. For both offensive and defensive teams, significant ($p<0.05$) differences exist between positional groups for game physical performance requirements. The results of the present study identified that wide receivers (WR) and defensive backs (DB) completed significantly ($p<0.05$) greater total distance, high-intensity running, sprint distance, and high-intensity acceleration and deceleration efforts compared to their respective offensive and defensive positional groups. Data from the present study provide novel quantification of position-specific physical demands of college football games and support the use of position-specific training in the preparation of NCAA Division I college football players for competition.

**Chapter 4 (Study 2 – Paper 2)**

The aims of the present study were to 1) examine positional impact profiles of NCAA division I college football players using global positioning system (GPS) and integrated accelerometry (IA) technology, and 2) determine if positional differences in impact profiles during competition exist within offensive and defensive teams. Thirty-three NCAA division I Football Bowl Subdivision players were monitored using GPS and IA (GPSports, Canberra, Australia) during 12 regular season games throughout the 2014 season. Individual player datasets (n = 294) were divided into offensive and defensive teams, and positional sub-groups. The intensity, number, and distribution of impact forces experienced by players during competition were recorded. Positional differences were found for the distribution of impacts within offensive and defensive teams. Wide receivers (WR) sustained more very light and light to moderate (5-6.5 G force) impacts than other position groups, while the running backs (RB) were involved in more severe (>10 G force) impacts than all offensive position groups, with the exception of the quarterbacks (QB) ($p<0.05$). The defensive back (DB) and linebacker (LB) groups were subject to more very light (5.0-6.0 G force) impacts, and the defensive tackle (DT) group sustained more heavy and very heavy (7.1-10 G force) impacts than other defensive positions ($p<0.05$). Data from the present study provide novel quantification of positional impact profiles related to the physical demands of college football games and highlight the need for position-specific monitoring and training in the preparation for the impact loads experienced during NCAA Division I football competition.

**Chapter 5 (Study 3 – Paper 3)**

The aims of the present study were to examine the movement demands of pre-season practice in National Collegiate Athletic Association (NCAA) division I college football players using portable global positioning system (GPS) technology and to assess perceived wellness associated with pre-season practice to determine if GPS-derived variables from the preceding day influence perceived wellness the following day. Twenty-nine players were monitored using GPS receivers (Catapult Innovations, Melbourne, Australia) during 20 pre-season practices. Individual observations (n=550) were divided into offensive and defensive position groups. Movement variables including low-, medium-, high-intensity, and sprint distance, player load, and acceleration and deceleration distance were assessed. Perceived wellness ratings (n=469) were examined using a questionnaire which assessed fatigue, soreness, sleep quality, sleep quantity, stress, and mood. A one-way ANOVA for positional movement demands, and multi-level regressions for wellness measures were used, followed by post-hoc testing to evaluate the relational significance between categorical outcomes of perceived wellness scores and movement variables. Results demonstrated significantly ($p<0.05$) greater total, high-intensity, and sprint distance, along with greater acceleration and deceleration distances for the DB and WR position groups compared to their respective offensive and defensive counterparts. Significant ($p<0.05$) differences in movement variables were demonstrated for individuals who responded more or less favorably on each of the six factors of perceived wellness. Data from the present study provide novel quantification of the position-specific physical demands and perceived wellness associated with college football pre-season practice. Results support the use of position-specific training and individual monitoring of college football players.

**Chapter 6 (Study 4 – Paper 4)**

The aim of the present study was to quantify the individual practice and game loads throughout an NCAA division I football season to determine if significant differences exist between the practice loads associated with pre-season training camp and those undertaken during the in-season period. Thirty-one NCAA division I football players were monitored using GPS and IA (MinimaxX S5; Catapult Innovations, Melbourne, Australia) during 22 pre-season practices, 36 in-season practices, and 12 competitions. The season was divided into four distinct phases for data analysis: pre-season week 1 (pre-season1), pre-season week 2 (pre-season2), pre-season week 3 (pre-season3), and 12 in-season weeks. Individual IA datasets represented players from every offensive and defensive position group (WR: n=5), (OL: n=4), (RB: n=4), (QB: n=2), (TE: n=3), (DL: n=4), (LB: n=4), (DB: n=5). Data were set at the practice level, where an observation for each player's maximum player load (PLMax) or mean player load (PLMean) from each training camp phase was referenced against each player's respective PL from each game, Game -4, Game -3, or Game -2 practice session. Notable results included significantly ($p<0.05$) greater PLMax values attributed to pre-season1 compared to PL resulting from all in-season practices, and significantly ($p<0.05$) higher cumulative PL reported for pre-season1, 2, and 3 compared to every in-season week.

Data from the present study augment our understanding of the practice demands experienced by NCAA division I college football players, and provide scope for the improvement of pre-season practice design and physical conditioning strategies for coaches seeking to optimize performance.

**Chapter 7 (Study 5 – Paper 5)**

The present study assessed the influence of movement demands resulting from weekly practice sessions and games, on perceived wellness measurements taken post-game (Game +1) and 48 hours pre-game (Game -2) throughout the in-season period in National Collegiate Athletic Association (NCAA) division I football players.  Thirty players were monitored using GPS receivers (Catapult Innovations OptimEye S5, Melbourne, Australia) during 12 games and 24 in-season practices.  Movement variables included low-intensity distance, medium-intensity distance, high-intensity distance, sprint distance, total distance, player load, and acceleration and deceleration distance.  Perceived wellness, including fatigue, soreness, sleep quality and quantity, stress, and mood, was examined using a questionnaire on a 1-5 Likert scale.  Multi-level mixed linear regressions determined the differential effects of movement metrics on perceived wellness.  Post-hoc tests were conducted to evaluate the pair-wise differentials of movement and significance for wellness ratings.  Notable findings included significantly ($p<0.05$) less player load, low-intensity distance, medium-intensity distance, high-intensity distance, total distance, and acceleration and deceleration distance at all intensities, in those reporting more favorable (4-5) ratings of perceived fatigue and soreness on Game +1.  Conversely, individuals reporting more favorable Game +1 perceived stress ratings demonstrated significantly ($p<0.05$) higher player load, low-intensity and medium-intensity distance, total distance, low-intensity and medium-intensity deceleration distance, and acceleration distance at all intensities than individuals reporting less favorable (1-2) perceived stress ratings.  Data from the present study provide a novel investigation of perceived wellness associated with college football practice and competition.  Results support the use of wellness questionnaires for monitoring perceived wellness in NCAA division I college football players.

## List of Publications

1. **Wellman, A.W.**, S.C. Coad, G.C. Goulet, and C.P. McLellan. Quantification of competitive game demands of NCAA division I college football players using global positioning systems. Journal of Strength and Conditioning Research 30: 11-19, 2016.

2. **Wellman, A.W.**, S.C. Coad, G.C. Goulet, and C.P. McLellan. Quantification of accelerometer derived impacts associated with competitive games in NCAA division I college football players. Journal of Strength and Conditioning Research 31: 330-338, 2017.

3. **Wellman, A.W.**, S.C. Coad, P.J. Flynn, M. Climstein, and C.P. McLellan. Movement demands and perceived wellness associated with pre-season training camp in NCAA division I football players. Journal of Strength and Conditioning Research, 31: 2704–2718, 2017.

4. **Wellman, A.W.**, S.C. Coad, P.J. Flynn, T.K. Siam, and C.P. McLellan. A comparison of pre-season and in-season practice and game loads in NCAA division I football players. Journal of Strength and Conditioning Research, In Press, 2017.

5. **Wellman, A.W.**, S.C. Coad, P.J. Flynn, T.K. Siam, and C.P. McLellan. Perceived wellness associated with practice and competition in NCAA division I football players. Journal of Strength and Conditioning Research, In Press, 2017.

## List of Conference Proceedings

1. **Wellman, A.W.**, S.C. Coad, G.C. Goulet, and C.P. McLellan. Quantification of competitive game demands of NCAA division I college football players using global positioning systems. Presented at the National Strength and Conditioning Association National Conference and Exhibition, 8-11 July, 2015, Orlando, FL.

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## List of Symbols and Abbreviations

### Symbols

| | |
|---|---|
| Dot (·) | above any symbol indicates a time derivative |
| < | less than |
| > | greater than |
| ± | plus or minus |
| % | percent |
| p | statistical significance |
| º | degree |

### Units of Measurement

| | |
|---|---|
| ANOVA | analysis of variance |
| AU | arbitrary units |
| $b \cdot min^{-1}$ | beats per minute |
| CI | confidence interval |
| cm | centimeter |
| CV | coefficient of variance |
| d | Cohen's effect size statistic |
| g | gram |
| G | gravitational force |
| Hz | hertz |
| kg | kilogram |
| $km \cdot h^{-1}$ | kilometers per hour |
| m | meters |
| $m \cdot s^{-1}$ | meters per second |
| $m \cdot s^{-2}$ | meters per second squared |

| | |
|---|---|
| mm | millimeter |
| $n^2$ | eta-square |
| OLS | ordinary least squares |
| pNN50 | time domain measre of heart rate variability |
| r | Pearson's product moment correlation coefficient |
| sec | seconds |

**Variables and Abbreviated Terms**

| | |
|---|---|
| ABQ | athlete burnout questionnaire |
| AFL | Australian football league |
| ANS | autonomic nervous system |
| ARF | Australian rules football |
| ASRM | athlete self-report measure |
| ATPase | enzyme catalyzing hydrolysis of adenosine triphosphate |
| BAM | brief assessment of mood |
| $Ca^{2+}$ | calcium ion |
| CK | creatine kinase |
| CMJ | countermovement jump |
| CNS | central nervous system |
| DALDA | daily analysis of life demands for athletes |
| DB | defensive back |
| DE | defensive end |
| DJ | depth jump |
| DT | defensive tackle |
| ECG | electrocardiogram |
| FBS | football bowl subdivision |
| GPS | global positioning systems |
| HF | high frequency |
| HFF | high frequency fatigue |
| HFnu | high frequency power expressed in normal units |

| | |
|---|---|
| HR | heart rate |
| HRmax | maximum heart rate |
| HRV | heart rate variability |
| IA | integrated accelerometer |
| $K^+$ | potassium ion |
| KE | knee extension |
| KF | knee flexion |
| LB | linebacker |
| LF | low frequency |
| LFF | low frequency fatigue |
| LFnu | low frequency power expressed in normal units |
| MVC | maximum voluntary contraction |
| n | number of subjects |
| $Na^+$ | sodium ion |
| NCAA | National Collegiate Athletic Association |
| NMF | neuromuscular fatigue |
| N-N | normal-to-normal intervals on an electrocardiogram |
| NRL | national rugby league |
| OL | offensive linemen |
| PF | peak force |
| PL | player load |
| PLmax | maximum player load |
| PLmean | mean player load |
| PNS | parasympathetic nervous system |
| POMS | profile of mood states |
| POMS-A | profile of mood states for adolescents |
| PP | peak power |
| Pre-season1 | week one of pre-season camp |
| Pre-season2 | week two of pre-season camp |
| Pre-season3 | week three of pre-season camp |
| PRFD | peak rate of force development |
| QB | quarterback |

| | |
|---|---|
| QRS | graphical deflections seen on an electrocardiogram |
| RB | running back |
| REST-Q Sport | recovery-stress questionnaire for athletes |
| RFD | rate of force development |
| RMSSD | root mean square of the successive differences |
| R-R | interval between successive R’s on an electrocardiogram |
| SD | standard deviation |
| SDNN | standard deviations of normal-to-normal intervals |
| SJ | squat jump |
| SNS | sympathetic nervous system |
| SPSS | statistical package for the social sciences |
| SSC | stretch shortening cycle |
| TE | tight end |
| TRIMP | training impulse |
| VJ | vertical jump |
| $VO_2max$ | maximum oxygem uptake |
| WR | wide receiver |

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# Chapter 1

## 1.1 Introduction

American football is a high-intensity collision sport requiring high levels of muscular strength, power, speed, agility and aerobic and anaerobic capacities in addition to position specific skill requirements (196). The NCAA football season consists of twelve regular season games between the months of August and December, followed by conference championship games and bowl games. Contingent upon on a team's success throughout the regular season, the competitive season may span 23 weeks, including a four week pre-season period, a 13-14 week in-season period, and a 4-6 week post-season period. Over the course of the 13-14 week in-season period, twelve games are played on a weekly basis, with one or two of these weeks dedicated as off or 'bye' weeks, in which games are not scheduled.

American NCAA football games consist of four fifteen minute quarters, with one-minute intermissions between the first and second quarter and the third and fourth quarter. The intermission between the second and third quarter, referred to as the half-time break, is 20 minutes in duration. The game clock may be stopped for any of the following reasons:

- a touchback
- forward pass ruled incomplete
- the ball carrier goes out of bounds
- a charged team timeout
- a legal kick down ends
- a return kick is made
- a team is awarded a first down either through play or by penalty
- an injury to any participant
- an instant replay challenge
- a media timeout
- a participant's helmet is removed purposely or inadvertently during the course of play
- following a play that results in scoring for either team
- any reason deemed necessary by the officials (175)

In 2013 the average number of offensive and defensive plays completed during competitive games was 71.5 and 71.1, respectively (174). While the duration of a game may exceed three hours due to stoppages of play, and given the average length of each play has been reported to be 5.23 seconds (111), individual playing time is far less. In addition to the game clock, a separate play clock of either 40 or 25 seconds is used to record the duration between the end of one play and the beginning of the next. When an official signals that the ball is dead, the offense is given 40 seconds to commence the subsequent play. The play clock is set at 25 seconds if the officials signal the game clock to be stopped for any of the following reasons: penalty administration, charged team timeout, media timeout, an injury to an offensive player, measurement, team awarded a first down, following a kick or a score, the start of each period, instant replay review, or any other administrative stoppage. All players must wear a helmet, hip pads, knee pads, thigh pads, a jersey, a mouthpiece, pants, shoulder pads, and socks.

In American football, three phases of play exist, namely offense, defense and special teams. Special teams refer to any phase of play in which kicking of the football is involved. Offense refers to the phase of possessing the football, whereby players are allowed to run or pass the football in attempt to advance towards the end zone. The defending team, not in possession of the football, attempts to oppose the offensive team through the use of physical force and tactical planning.

Eleven players are permitted to participate on each play (175). The ball is placed on the line of scrimmage, and each play is commenced with the snap of the ball by the offensive team. The line of scrimmage is the yard line that defines the vertical plane passing through the point of the ball nearest to a team's own goal line (175). Legally snapping the ball is handing or passing it backward from its position on the ground with a quick and continuous motion of the hand or hands (175). The offensive team is provided four attempts, referred to as 'downs', to advance the ball ten or more yards. The offensive team is awarded a first down when the team has successfully advanced the field position of the ball ten yards or more. If the offense does not advance the ball ten or more yards within the four downs, the opposing team gains control of the ball.

Official rules dictate seven offensive players must be aligned on the line of scrimmage, while the remaining four must be behind the line of scrimmage (175). The defensive team is permitted to align themselves in any manner, provided they are behind the line of scrimmage, on the side nearest their own end zone, however structured positions are utilised in order to gain a tactical advantage (175).

College football teams that are similar to other collision-based team sports (44, 138), participate in an intensified pre-season training camp that typically commences 4-5 weeks prior to the first competition and is associated with a maximum of 29 practice sessions (176). National Collegiate Athletic Association rules govern practice guidelines, permitting teams to designate up to four days for multiple practices, provided the practices do not exceed five total hours combined, and they do not occur on consecutive days (176). Pre-season training camp in collision sports similar to American football is characterized by high exercise loads associated with practice demands, and the resulting cumulative fatigue that may contribute to overreaching and underperformance in team sport athletes (27, 135).

Programming training loads during the pre-season practice period, which maximize positive physiological adaptations, and minimize excessive fatigue that may be associated with maladaptation, can be challenging for coaches and performance staff. While the programming of individual training load prescriptions presents a difficulty in team sports, the prudent monitoring of the individual response to these loads is fundamental for maximizing positive training adaptations (20). The use of GPS and IA to quantify movement demands in contact team sport is commonplace (9, 74, 160, 148, 156, 213), however limited studies (56) have utilized GPS and IA to examine the movement demands inherent to participation in NCAA division I college football.

In American football, each position group has distinct physiologic and biomechanical demands associated with specific technical and tactical requirements (141), however uncertainty exists regarding the position-specific movement demands of NCAA football practice and competition. Given the widespread inclusion of GPS technology in collegiate American football programs, a detailed assessment of competitive movement profile characteristics will provide sports performance specialists with quantified information on game demands. A more comprehensive understanding of the demands of NCAA football practice and competition will augment our understanding of the position-specific movement demands of NCAA college football players, and allow sport coaches to individualize training programs for the purpose of performance enhancement.

Monitoring the training process involves not only objectively quantifying the volume and intensity of physical activity completed, but also the relative physiological and psychological stress imposed as a result of training (97). Previous research in contact team sport, with competitive demands indicative of NCAA division I football, has examined athlete perceived wellness in response to training and competition (44, 64, 83, 153, 230) however similar investigations in NCAA division I football are scant (72). Subjective measures of mood state and well-being are efficient, inexpensive, and non-invasive (150), have demonstrated sensitivity to training stress, exhibiting a dose-response relationship with training load (190, 209), and have been established to be as effective as objective measures in identifying training stress (31).

In elite contact team sport, significant correlations have been reported between fluctuations in daily training load and changes in subjective ratings of wellness (27). During intensified periods of competition in sports characteristic of American football, significant changes in perceived well-being accompany performance decrements, decreases in neuromuscular power, and increases in biochemical markers of muscle damage (116). Currently, the effects of high-intensity, intermittent exercise and the repeated blunt force trauma experienced by NCAA football players, on perceptions of well-being, remain largely unknown. Accordingly, an analysis of the position-specific movement demands of practice and competition, and the perceived wellness associated with these demands, may provide insight into the programming of practice sessions and the early detection of maladaptation resulting from improperly prescribed loads.

## 1.2 Purpose of the Research

Despite the popularity of American football, no studies have elucidated the positional movement demands of practice and competition in NCAA division I football players, nor have the perceived wellness responses, relative to these specific movement demands, been examined.

The quantification of movement demands via GPA and IA in team sports similar to American football, including Rugby League, Rugby Union, and Australian rules football, indicate significant differences exist in high-intensity movements including acceleration and deceleration efforts (213, 242), and maximal speed (33, 160) between position groups. DeMartini et. al. (56) reported movement profile characteristics associated with pre-season practice sessions in NCAA division I college football by examining the physical demands of division I college football players during nine pre-season practices over the course of eight days, utilizing GPS to evaluate total distance covered and running velocity characteristics. The main findings reported by DeMartini et. al. (56) were that non-linemen covered greater total distance and sprint distance than linemen, who covered greater distance at slower speeds. To date, ambiguity remains regarding the position-specific demands of NCAA division I college football players during pre-season and in-season practice and competition.

## 1.3 Significance of the Research

Within the last 5-10 years, substantial emphasis has been placed on the quantification of athlete movement characteristics and monitoring of the training and recovery process in NCAA division I football programs. Despite this, no studies have examined the positional movement demands associated with practice and competition, or the resulting perceptions of wellness that are associated with these demands. Consequently, the programming of practice loads and recovery protocols have been based largely on anecdotal evidence and coaching intuition. The significance of the present research is that the quantification of positional pre-season and in-season practice and game demands provides insight for coaches and sports performance practitioners to optimally program practice loads, which mitigate the deleterious effects of excessive fatigue and maximize competitive performance. Additionally, the novel examination of perceived wellness associated with these physical demands provides information regarding the adaptive response of the athletes to the training program, allowing coaches to make prudent adjustments to individual and team training and practice schedules.

### 1.4 Research Questions

The present research will investigate a number of questions associated with the examination of NCAA division I football movement demands and the resulting perceived wellness associated with these demands.

1. What are the positional movement demands associated with competitive games? (Study 1)
2. Do significant differences in movement variables exist between positions? (Study 1).
3. What are the positional impact profiles resulting from competitive games? (Study 2).
4. Do significant differences in impact profiles exist between positions? (Study 2).
5. What are the positional movement demands of pre-season training camp practices and how do these demands impact perceived wellness the following day? (Study 3).
6. Do significant differences exist between positional groups for pre-season training camp practice sessions? (Study3).
7. Which GPS-derived movement variables influence differential ratings of wellness? (Study 3).

8. How do pre-season training camp practice loads compare with in-season practice and game loads? (Study 4)
9. How do game-day movement demands affect perceived wellness the following day? (Study 5).
10. What impact do weekly in-season practice sessions have on perceived wellness two days prior to games? (Study 5).

**1.5 Research Progress Linking the Studies**

The present research examined the physical movement demands associated with pre-season training camp practice, in-season practice sessions, and competitive games, along with the resulting perceptions of wellness associated with these demands. To achieve this aim, five research studies were undertaken and are presented as chapters three, four, five, six, and seven of the thesis. Each study within the present thesis was designed to build upon the preceding chapter to enhance our understanding of the pre-season and in-season physical demands of NCAA division I football and develop the primary aim of the thesis. The most critical component of the in-season period is game-day performance, and therefore, the rational for Study 1 was to establish the position-specific GPS-derived movement demands associated with competition in NCAA division I football.

Following the establishment of the position-specific movement demands, including running distance and acceleration and deceleration distance at all intensities, an examination of positional impact profiles associated with competitive games was undertaken. Low-intensity impacts may be associated with walking and running, while high-intensity impacts are likely attributed to high-intensity changes of direction, falling to the ground, landing from jumps, and collisions from blocking and tackling. Analysis in contact team-sport similar to American football has demonstrated positional differences in the quantity and intensity of impacts associated with competition.

Study 3 increased the scope of our understanding of the movement demands and the resulting perceived wellness associated with pre-season training camp practice. The rationale for this study was to incorporate the GPS and IA protocols utilized in study 1 and 2, while simultaneously investigating the daily perceived wellness of athletes throughout training camp. Pre-season training camp is highlighted by frequent practice sessions that are intense in nature, and as such, represents a unique period during the NCAA football season. The quantification of the physical demands of this period, along with the perceived wellness stemming from these demands, provides insight to members of the coaching staff from which judicious decisions on practice planning may be developed.

Study 4 examined the IA variable of Player Load resulting from pre-season training camp practice compared to that resulting from in-season practice and games. The rationale for this investigation was to determine if pre-season physical demands adequately prepare NCAA division I football players for the demands encountered during the in-season competitive period. Additionally, the IA variable of player load was selected for this study due to the difficulty of several college football teams to collect GPS data throughout the entirety of the in-season period. Data collection via GPS is reliant on satellite connection, and thus is predicated upon conducting all practice sessions outdoors. Throughout much of the United States, GPS data collection becomes problematic in the latter half of the competitive season and throughout the NCAA division I bowl preparation period for many teams, and thus player load provides a consistent metric, which coaches and performance staff may use for the appropriate programming of training and practice sessions.

NCAA division I football competition is characterized by high velocity movement, rapid acceleration and deceleration efforts and blunt force trauma resulting from collisions with opponents and the ground during blocking and tackling. The rationale for Study 5 therefore was to examine which game-day GPS and IA-derived movement metrics were associated with differential ratings of wellness the following day. Additionally, study 5 examined the impact of in-season weekly practice sessions on perceived well-being 2 days prior to games. The collective results of studies 1-5 may be used by sport coaches and performance staff to guide the planning of practice loads and the monitoring of individual player tolerance to programmed loads, throughout the course of an NCAA division I football season.

The research undertaken in the present thesis aimed to comprehensively investigate the position-specific physical demands, and subsequent perceived wellness associated with these demands, during the pre-season and in-season competitive periods in NCAA division I football players. There are several novel aspects within the five studies presented in the present thesis, including the GPS and IA-derived position-specific physiological demands of games, and in-season and pre-season practice sessions. Additionally, a novel examination of the perceived wellness associated with movements demands of pre-season training camp practice and in-season competitive games was completed. Independently and collectively, each of the five experimental studies detailed in the present thesis represent a more robust investigation of NCAA division I football movement demands and perceived wellness than previously reported, and provide increased understanding of the movement demands and the subsequent perceived wellness in NCAA division I football players.

# Chapter 2
# Overview of the Literature

## 2.1 NCAA Division I College Football

### 2.1.1 Physical Demands Associated with NCAA Division I College Football

American football is a team-based field sport, which places a heavy demand on the physiological systems of those who participate. American football is a high-intensity anaerobic sport characterised by brief intense bursts of work during plays and short rest periods between plays, with on-field success highly influenced by technical and tactical skill, and physiological characteristics including speed, change-of-direction ability, strength, and power (196). Football players must possess adequate aerobic capacity to provide power throughout a long, intermittent duration and to recover quickly in short time intervals (185). Additionally, there is a need for players to develop high maximum anaerobic power to enable them to perform the powerful movements of repeated acceleration and deceleration throughout the course of competitive games (185). American football has been classified as an acyclic sport comprised of functions such as backpedaling, decelerating, accelerating and tackling, often performed during a given play (185). These high-intensity movement demands, further influenced by repeated blunt force trauma experienced by players during high impact collisions and repetitive contact inherent to the sport, provide additional stress not commonly encountered in other forms of physical activity (216). Studies in American football (105, 142) and team-based collision sports such as Rugby League (158), have suggested that repeated high-intensity collisions during competition are associated with significant increases in markers of skeletal muscle damage, which has been identified as a key consideration associated with the post-match recovery period and is of importance when developing in-season training programs in preparation for weekly competitions.

Currently, the most appropriate and effective means for manipulating mode, frequency, intensity, and duration of each aspect of training for American football is unknown. It has been suggested, however, that training programs should closely mimic the specific demands of the sport (111). Due to the unique physical and physiological demands of NCAA division I football competition, specificity of training is a critical concept to consider when developing athletic performance enhancement programs for football (111). To date, limited empirical data exist demonstrating the physiological requirements of NCAA football competition, and data that do exist are equivocal (111, 194). Despite the widespread popularity of college football, few studies (111, 194) have investigated the physiological demands of practice and competition in college football. Rhea et al. (2006) (194) investigated discrete periods of games, in the form of at least four series (a group of plays), of high school, collegiate, and professional games and reporteded the duration of run and pass plays in college football to be 5.13 ± 1.45 seconds and 5.96 ± 1.62 seconds, respectively. The average time for recovery between plays and stoppages between plays was 33.98 ± 4.19 seconds and 90.66 ± 47.24 seconds, with an average exercise to recovery ratio of 1:6.1 during competition (194). Alternatively, in an analysis of division I college football competition, Iosia and Bishop (2008) (111) measured the mean duration of exercise-to-rest ratios during the course of six televised division I college football games and reported the average duration of play to be 5.23 ± 1.61 seconds. Analysis of run and pass plays specifically, was determined to be 4.86 ± 1.42 seconds and 5.60 ± 1.71 seconds, respectively, with the minimum and maximum duration for all plays analysed, both run and pass, determined to be 1.44 – 15.01 seconds (111). The overall mean for duration of rest between play was 46.9 ± 34.3 seconds, and excluding halftime, the average rest time between series was 11.5 ± 4.3 minutes (111). Iosia and Bishop (111) noted the large standard deviation (SD) was caused by six types of stoppages in play that included team timeouts, television timeouts, penalty, injury, measurement, and end of quarter. Several factors may contribute to the duration of plays, among which include the style of play of the offensive the team, time remaining in the competition, and the point differential.

While previous research (111, 194) has provided a rudimentary overview of exercise to rest ratios experienced by players during collegiate football, no studies have quantified the demands of on-field performance, and the positional demands of competition are unknown. Quantification of the specific movement characteristics and physiological demands of college football competition is paramount for the development of sport-specific training programs and recovery protocols to optimise performance and potentially reduce the incidence of injury. Global positioning system technology has been used to quantify the physical demands of team sports including Rugby Union and Rugby League (10), 43, 50, 74, 198), Australian rules football (23, 202, 240), soccer (30, 234), field hockey (75, 238), and cricket (162). These data (10, 23, 43, 50, 74, 198, 202, 240) have provided specific information on the demands of contact team sport similar to American football, and the associated physiological responses of professional, semi-professional, and junior elite athletes. Data on the physical demands of college football players may be used to determine position-specific performance characteristics of college football to aid in the development of training programs that mimic practice and competition.

Despite its widespread popularity, only one study has incorporated portable GPS technology to describe the physical demands of college football practice. DeMartini et. al. (2011) (56) utilised GPS device (MinimaxX 2.5; Catapult innovations, Melbourne, Australia) to identify the physical demands imposed on division I football players during nine preseason practices training in hot conditions. The authors (56) examined player position and playing status characteristics of practice time (min), distance covered (m), percentage of distance covered in different velocity zones (%), and maximal and mean heart rate ($b \cdot min^{-1}$). DeMartini et. al. (56) reported that non-linemen covered more distance (3,532 ± 943 m), spent a larger percentage of distance covered in practice at high velocities (>16 $km \cdot h^{-1}$) (10.7 ± 3.1%), and reached a higher maximum heart rate (HRmax) (201 ± 9 $b \cdot min^{-1}$) than linemen who covered total distance of 2,573 ± 489 m, spent 3.1 ± 2.4% of distance covered at high velocity (>16 $km \cdot h^{-1}$), and reached a HRmax of 194 ± 11 $b \cdot min^{-1}$. Playing status did not significantly affect distance covered at high velocity (>16 $km \cdot h^{-1}$) during practice, with starters (5.9 ± 4.8%) and non-starters (8.4 ± 4.2%) showing similar percentages of distance covered (56). The work of DeMartini et. al. (56) has added to our understanding of the physiological demands of college football, however no studies have examined position-specific movement patterns and training load considerations over an extended in-season period of competition. A greater understanding of the specific demands imposed upon players during practice and competition is needed to develop position-specific training and recovery programs, to achieve optimal on-field performance and reduce injury risk. Due to the physical and psychological demands associated with practice, competition, recovery, training, team and individual meetings, along with academic and media obligations of the 22-24 week in-season phase, it is imperative that coaches and performance staff utilise a monitoring system to properly manage student athlete fatigue and wellbeing. Investigation of college football competition incorporating portable GPS units provides extended scope for an improved understanding of the physiological movement demands of practice and competition to optimise training rationales and on-field performance. The present literature search was conducted using search databases, namely PubMed, Google Scholar, and Bond University library. Additionally, a manual search was conducted on reference lists of selected articles to augment the literature.

### 2.1.2 Anthropometric and Physiological Characteristics of NCAA Football Players

College football requires speed, change-of-direction ability, strength and power (196), and as such, players participate in year-round, programmed training designed to enhance athletic performance and reduce the likelihood of injury. The addition of state-of-the-art training protocols, certified training professionals, biomechanically precise training equipment, and monitored nutrition, may be partly responsible for the increased size (4) and performance of present-day players when compared to those of the past (112).

Melvin et. al (2014) (164) examined the body composition of NCAA division I football players and reported offensive and defensive linemen to have significantly ($p<0.05$) more lean mass and fat mass than all other positions, as well as significantly ($p<0.05$) higher percent body fat than all positions, excluding quarterbacks. The following table (Table 1) represents the means and standard deviations for height (cm), mass (kg), and percent body fat of NCAA division I football players by position:

**Table 1.** Means ± Standard Deviations for Height, Mass, and Body Fat Percentage of NCAA Division I Football Players

| Position | Height (cm) | Mass (kg) | % Body Fat |
|---|---|---|---|
| Quarterbacks | 186.6 ± 2.7 | 96.9 ± 2.1 | 18.1 ± 2.1 |
| Running Backs | 178.0 ± 5.0 | 94.4 ± 10.2 | 13.9 ± 2.0 |
| Tight Ends | 191.7 ± 5.0 | 109.7 ± 6.6 | 17.9 ± 2.8 |
| Linebackers | 187.5 ± 3.4 | 103.5 ± 3.9 | 17.0 ± 2.9 |
| Defensive Backs | 180.7 ± 2.8 | 89.4 ± 6.3 | 14.0 ± 2.2 |
| Place Kickers | 176.2 ± 2.5 | 87.5 ± 7 | 16.6 ± 3.9 |
| Defensive Line | 190.6 ± 4.8 | 132.2 ± 9.4 | 22.3 ± 2.3 |
| Offensive Line | 195.0 ± 4.2 | 136.5 ± 11.0 | 24.4 ± 2.2 |
| Wide Receivers | 183.1 ± 5.2 | 88.0 ± 6.6 | 14.4 ± 2.2 |

The NFL holds an annual scouting combine, which includes a battery of physical assessment procedures for 300-350 of the most promising collegiate players in the nation and includes anthropometric assessments, physical skill tests, position-specific drills, interviews, medical and drug tests, and mental acuity assessments. The physical tests undertaken as part of the NFL combine are designed to measure speed, power, change-of-direction ability, and strength, to establish a system of player ranking for the purposes of recruitment, and to provide a comprehensive database of individual player physical characteristics. The data from tests undertaken by players during the combine provide excellent measures of the physical abilities of players being drafted into the NFL (196). Robbins et. al. (2013) (196) compared positional anthropometric and NFL combine performance levels in elite college American football players over the three year period from 1999 to 2001 to the three year period from 2008 to 2010. Of the fifteen positions examined, players in three position groups were lighter (center, offensive tackle, tight end) and in six groups were heavier (cornerback, defensive tackle, free safety, quarterback, strong safety, wide receiver) in 2008 to 2010 than the previous years, with six (defensive end, fullback, inside linebacker, offensive guard, outside linebacker, running back) groups showing no significant difference. With respect to height, players in three position groups (cornerback, outside linebacker, running back) were shorter and those in two position groups (quarterback, tight end) were taller in 2008 to 2010 as compared to the 1999 to 2001 group. Over the 3 sprint distances (9.1 m, 18.3 m, 36.6 m), every position was faster in two or three distances in the 2008-10 group. Change-of-direction measures demonstrated players in 7 of the 15 groups, namely cornerback, defensive end, defensive tackle, free safety, outside linebacker, running back, and wide receiver, exhibited worse performance in the 20 yard (18.3 m) shuttle in the 2008-10 group compared to the 1999-2001 group. However, all but three position groups (defensive tackle, free safety, strong safety) exhibited better performance in the 3-cone drill in 2008-10 group as compared to the earlier group. Regarding jump measures, players in 5 positions (center, cornerback, wide receiver, offensive guard, quarterback) displayed worse performance in the vertical jump, and players in 5 positions (cornerback, inside linebacker, outside linebacker, tight end, wide receiver) exhibited better performance in the horizontal jump in the 2008-10 group as compared to the 1999-2001 group. Of the 13 positions performing the bench press, all but four (center, free safety, fullback, tight end) displayed enhanced performance in the 2008-10 group compared to the earlier group (196).

The following table (Table 2) lists the 2014 averages by position for all scouting combine participants (Unpublished data received September 5, 2014 from Jeffrey Foster, President National Football Scouting, Inc.

**Table 2**. 2014 NFL Scouting Combine Averages by Position

| 2014 Averages By Postion For All Participants | | | | | | | |
|---|---|---|---|---|---|---|---|
| **College Position** | **Height (cm)** | **Weight (kg)** | **Body Fat %** | **40 yd. sprint (36.6 m)** | **Vertical Jump (cm)** | **Horizontal Jump (cm)** | **20 yd. shuttle (18.3 m)** |
| **Cornerback** | 180.7 | 88.2 | 9.4 | 4.53 | 92.7 | 312.4 | 4.21 |
| **Free Safety** | 184.2 | 91.8 | 8.4 | 4.56 | 87.6 | 302.3 | 4.12 |
| **Strong Safety** | 181.6 | 94.1 | 8.4 | 4.63 | 88.9 | 299.7 | 4.35 |
| **Defensive End** | 192.1 | 120.9 | 15.5 | 4.82 | 83.8 | 294.6 | 4.45 |
| **Defensive Tackle** | 191.1 | 138.6 | 22.7 | 5.12 | 73.7 | 266.7 | 4.67 |
| **Nose Tackle** | 187.3 | 150.5 | 26.2 | 5.33 | 67.3 | 238.8 | 4.75 |
| **Inside Linebacker** | 187.3 | 109.5 | 11.5 | 4.80 | 85.1 | 294.6 | 4.30 |
| **Outside Linebacker** | 190.2 | 110.9 | 11.6 | 4.71 | 88.9 | 302.3 | 4.23 |
| **Center** | 191.5 | 139.5 | 22.7 | 5.21 | 67.3 | 266.7 | 4.62 |
| **Offensive Guard** | 193.0 | 143.2 | 22.3 | 5.27 | 66.0 | 256.5 | 4.73 |
| **Offensive Tackle** | 196.9 | 142.7 | 21.1 | 5.19 | 69.9 | 266.7 | 4.69 |
| **Quarterback** | 189.2 | 100.5 | 13.3 | 4.87 | 76.2 | 276.9 | 4.29 |
| **Fullback** | 187.6 | 115.9 | 13.3 | 4.92 | 78.7 | 279.4 | 4.47 |
| **Running Back** | 179.1 | 96.4 | 8.7 | 4.59 | 88.9 | 304.8 | 4.26 |
| **Tight End** | 194.0 | 115.9 | 12.2 | 4.75 | 81.3 | 297.2 | 4.39 |
| **Wide Receiver** | 184.5 | 91.8 | 6.7 | 4.53 | 88.9 | 307.3 | 4.19 |
| **Place Kicker** | 181.6 | 87.3 | 11.6 | N/A | N/A | N/A | N/A |
| **Punter** | 188.9 | 97.7 | 12.4 | N/A | N/A | N/A | N/A |

In American football, the defense is comprised of three commonly recognised position groups: 1). Defensive Line: includes defensive end, nose tackle, and defensive tackle, 2). Linebackers: inside linebacker and outside linebacker, and 3). Defensive Backs: cornerback, free safety, and strong safety. With reference to Table 2, defensive lineman commonly possess higher levels of body mass and body fat, coupled with slower sprint times and lower jump testing values when compared to linebackers and defensive backs. Linebackers are typically larger than defensive backs, but smaller than defensive linemen. This position group is also characterised by sprint times that are faster than defensive linemen, but slower than defensive backs. Due to positional demands, defensive backs have less body mass, lower levels of body fat, faster sprint times, and jump higher than defensive linemen and linebackers.

Offensively, five position groups are generally recognised, including 1). Offensive Line: center, offensive guard and offensive tackle, 2). Tight End, 3). Wide Receiver, 4) Quarterback, 5) Running Back, which includes the fullback position. As evidenced in Table 2, offensive linemen, like defensive linemen, have higher levels of body mass and body fat, and subsequently, slower sprint times along with lower jump testing values than the other offensive position groups. Tight ends, quarterbacks and fullbacks ordinarily possess higher levels of body mass and body fat than wide receivers and running backs, but less than offensive linemen. Wide receivers and running backs are typically smaller, leaner, faster, and display higher jump testing values than the other offensive position groups. The varying anthropometric and physiological characteristics that exist within positional groupings in American football present discreet challenges to coaches and performance staff seeking to improve performance that may be unlike other team sports.

## 2.2 Global Positioning Systems (GPS)

### 2.2.1 Performance Analysis Using GPS

Global positioning system technology had been used to quantify the physical demands of contact team sports such as professional Rugby League (9, 74, 54), Rugby Sevens (92), Australian Football League (AFL) (148, 240, 221), and Rugby Union (50, 156). The quantification of practice and game demands of NCAA division I college football players, in addition to information regarding the physiological responses associated with these demands, will allow sport coaches to tailor training programs that replicate the specific demands of American Football. Although GPS technology is widely used in contact team sports for both game and practice analysis, current literature describing the physical demands of American football training and competition is limited (56).

In the AFL, teams collect physical performance data using GPS devices, which are commonly used in research to provide a greater understanding of the factors that affect performance (133, 148, 240). The primary information sought by coaches, relating to game demands, are positional movement patterns including distances, velocities, and accelerations

(240). Wisbey, et. al. (2010) (240) used GPS technology to describe positional differences in movement patterns of nomadic players, defenders, and forwards in AFL athletes throughout a season. Results showed the typical player in AFL football covered 12.2 ± 1.9 km in total distance and completed 246 ± 47 moderate accelerations per game. Additionally, data indicated that physical demands of playing positions varied substantially (240). Nomadic players covered more distance, had higher exertion indices (exertion index was based on the sum of a weighted instantaneous speed, a weighted accumulated speed over 10 sec., and a weighted accumulated speed over 60 sec.) and increased running at velocities greater than 18 $km \cdot h^{-1}$ than fixed position players. This highlights the necessity of position specific training within AFL players (240).

The position-specific demands in professional Rugby League have also been evaluated (8). Austin et. al. (2013) (8) quantified the movement demands of forwards and backs (n=128) in the National Rugby League (NRL) competition throughout an entire 28 game season. The mean total distances covered in match play for forwards and backs were 5,964 ± 696 m and 7,628 ± 744 m, respectively (8). The high intensity running (>18 $km \cdot h^{-1}$) distance per match for forwards was 432 m and for backs was 749 m (8). Backs covered 42% greater distance and 34% higher frequency of high intensity running when compared to forwards (8). These results emphasise the importance of position-specific programming of training programs for NRL players (8). McLellan (2011) (160) monitored 22 elite Rugby League players during five regular season competition matches and reported that forwards covered a total distance of 4,982 ± 1,185 m, while backs covered 5,573 ± 1,128 m in a game. High-intensity running (>18 $km \cdot h^{-1}$) distances of forwards and backs was 232 m and 440 m per game (160). Substantial differences between McLellan et. al. (160) and Austin et.al. (8) were reported in measurements of high-intensity movement distances by forwards and backs in Rugby League match-play, perhaps indicating alterations in match physical performance characteristics between seasons or between games assessed in each study.

While the aforementioned studies (8, 160) examined the physical demands of Rugby League using two broad positional groupings, another study (9) analysed the movement demands of all nine individual playing positions (n=15 per individual position group) in professional Rugby League. Results indicated that backs covered an average of 7,802 m per game. This is substantially higher than the results reported by McLellan et. al. (160) (5,573 m), but similar to those described by Austin and Kelly (8) (7,628 m). Forwards covered a mean distance of 5,989 m, which again is higher than those reported by McLellan et. al. (160) (4,982 m), but similar to those provided by Austin and Kelly (8) (5,964 m). Researchers (9) indicated how easy it is to over- or underestimate actual values for each position when broad categories are used, evidenced by the fact that prop forwards covered 4,597 m, which was lower than hookers (6,988 m) and back row forwards (6,936 m). Hit-up forwards, wide running forwards, adjustables, and outside backs covered mean distances of 4,597 m, 6,209 m, 7,913 m, and 7,379 m, respectively. High intensity running (>18 $km \cdot h^{-1}$) for forwards averaged 388 m per game, compared with 432 m reported by Austin and Kelly (8) and 232 m per game reported to McLellan et. al. (160). The high-intensity running distance for the backs showed the fullbacks covered the most with 925 m, whereas forwards covered the least distance with 477 m. The average distance covered for the collective grouping of backs was 701 m, compared with that reported by McLellan et. al. (160) (440 m) and Austin and Kelly (8) (749 m). Consistent with investigations (8, 9, 160) demonstrating inter-positional differences in running distance resulting from competition, Gabbett et. al. (74) reported absolute distances covered for the adjustables (6,411 m), outside backs (6,819 m), and wide-running forwards (5,561 m), are greater than those for the hit-up forwards (3,569 m) (74).

Previous studies have not only examined match demands between position groups (8, 9, 160), but have also compared match demands between Rugby Leagues including Australian National Rugby League and European Super League (229), and the influence of playing standard on physical demands of professional Rugby League match play (76). Collectively, these data underscore the importance of quantifying the physiological demands of each individual position within field-based team sports. In doing so, coaches can deliver optimal training programs eliciting specific and appropriate adaptations, not only to position groups, but to individual athletes within these groups (9).

Investigations of the positional movement characteristics of American football practice and competition, similar to those conducted in Rugby League, would provide performance coaches with information allowing the design and implementation of position-specific training programs to meet the demands of competition. Large gaps currently exist regarding the physiological demands and movement patterns of practice and competition in American football players. To date, limited information exists (56) on the GPS-derived physical demands of NCAA division I college football practice, and published research (56) has evaluated NCAA football players as two broad positional categories, namely linemen and non-linemen. Consequently, the position-specific movements characterizing practice and competition in NCAA division I football players remain unknown.

### 2.2.2 Validity and Reliability of GPS Analysis

Detailed monitoring of an individual's training load can provide important information to coaches and athletes alike (97). Monitoring systems should provide time-effective data analysis and interpretation, enable efficient reporting of feedback, and possess adequate validity and reliability (97). In a study of AFL players Jennings et. al. (2010) (113) assessed the validity and reliability of 1 Hz and 5 Hz GPS units for distance measures during movement patterns common to team sports. Twenty players completed straight line movements of 10, 20, and 40 m at various speeds designated as walk, jog, stride, or sprint, gradual and tight change of direction courses (4 x 10 m straights and 8 x 5 m straights), and a team sport running simulation circuit. The GPS units underestimated the distance at both 1 Hz and 5 Hz when striding and sprinting over 10 and 20 m (113). The criterion distance was underestimated during the tight change of direction trials at all speeds, but higher sampling rates decreased error in both tight and gradual changes of direction, regardless of movement speed (113). The 1 Hz and 5 Hz units underestimated the total distance of the simulated team sport running circuit by 5.7 ± 0.6% and 3.7 ± 0.6%, respectively (113).

With improvements in GPS technology, from earlier 1 Hz and 5 Hz units to the 10 Hz and 15 Hz units now available, accuracy has also improved (115). Johnston et. al. (2014) (117)

utilised a team sport simulation circuit that was designed to assess the ability of 10 Hz and 15 Hz GPS units to measure team sport movement demands. The circuit included walking, jogging, running, and sprinting, along with accelerations and decelerations to replicate movements of team sport athletes. Result suggested that 10 Hz and 15 Hz GPS units are valid measures of total distance and more reliable measures of team sport movement demands when compared with both 1 Hz and 5 Hz units (117). Additionally, the inter-unit reliability results for distance covered, time spent, and number of low and high speed running efforts performed, indicated a moderate to good level of error (<10%) for both 10 Hz and 15 Hz GPS units (117). A study by Johnston et. al. (2012) (118) implemented a similar team sport simulation circuit, and revealed GPS to be an acceptable measure of total distance, peak speed, and number of efforts performed in specific velocity zones. Castellano et. al. (2011) (34) evaluated linear sprints of 15 m and 30 m utilizing 10 Hz GPS units and video cameras operating at a sampling frequency of 25 frames. The criterion distance was measured and electronic timing gates (TAG-Heuer, CP 250 Training Model, Switzerland) were utilized to obtain the criterion sprint time, accurate to 0.01 seconds. Distance measures were found to be reliable, showing greater stability over 30 m than 15 m (standard error of measurement 1.7-6.7% and 3.4-9.6%, respectively) and high intra- and inter-unit reliability (CV=0.7-1.3%) was reported (34).

Varley et. al. (2012) (231) demonstrated that GPS units sampling at 10 Hz were sufficient to quantify acceleration and deceleration running phases in team sports, however similar to other studies (93, 117, 191), as the running speed during exercise increased, so did the level of error. Regardless of the sport or sampling frequency, it appears that non-linear motions (232) and movements performed at speeds > 20 km·h$^{-1}$ (117) may increase GPS error. Specifically, Rawstorn et. al. (2014) (192) recommend caution be exercised when relying on GPS to quantify team sport athletes' performance, as rapid directional change in 20 m shuttle may decrease distance measurement accuracy and absolute reliability.

The present research utilized two commercially available GPS and IA units (SPI HPU, GPSports, Canberra, Australia) (MinimaxX S5; Catapult Innovations, Melbourne, Australia), both of which have demonstrated validity and reliability for quantifying team sport movement demands. The SPI HPU (GPSports, Canberra, Australia) units operated in a non-differential mode at a sampling frequency of 15 Hz, and contained integrated tri-axial accelerometers, which operated at 100 Hz. Research (117) has demonstrated SPI HPU units to be valid for measuring total distance and average peak speed in a team sport simulation circuit, with intraclass correlation values of interunit reliability reported to be 0.94 for high speed running (14.00 – 19.99 $km \cdot h^{-1}$) distance, 0.81 for very high speed running (> 20.00 $km \cdot h^{-1}$) distance, -0.20 for total distance, and – 0.14 for peak speed. The MinimaxX S5 (Catapult Innovations, Melbourne, Australia) GPS and IA unit sampled at 10 Hz and included triaxial accelerometers which operated at 100 Hz. Previous research (231) has demonstrated accuracy of similar units for quantifying movement demands in team sports.

Global positioning system analysis is a highly effective and time-efficient tool for monitoring workload within team sports (232), enabling scientists and performance coaches to investigate relationships between physical capacity and match performance (7). Several studies (45, 93, 113) have investigated the validity and reliability of GPS devices for measuring movement demands in team sports. The validity of GPS technology to measure team sport movement demands including sprinting, accelerations, and decelerations has improved with higher sampling rates (117), and while reliability may decrease with changes of direction and brief accelerations (2, 45, 93, 113, 192), this variability can be minimised by ensuring the same unit is used for individual players during all competition and training sessions (114).

### 2.2.3 GPS Analysis in Contact Team Sports

The development of GPS units with IA have allowed the physiological demands of team contact sport to be quantified (242). The primary aim of team sport research involving micro-technology has been the quantification of training and competitive demands utilizing GPS (49) The quantification of team-sport competition demands using GPS technology have been reported in sports similar in nature to American football, including Rugby League (9, 74, 160), Rugby Sevens (92), AFL (148, 221, 240), and Rugby Union (50, 156). Research (8, 156, 160) in team-sports utilising portable GPS technology indicate positional differences in movement characteristics during competition. No previous studies have reported the movement demands of NCAA division I football competition, consequently a lack of understanding exists regarding the demands of American football games. Investigations in team sports similar to American football, including Rugby League, Rugby Union, and Australian rules football, indicate significant differences exist in high-intensity movements including acceleration and deceleration efforts (148, 242), and maximal speed (33, 160) between position groups.

Research in similar collision-based team sport (108, 110, 173) has demonstrated unfavorable outcomes associated with acute increases in GPS-derived training loads. An examination (110) of the ratio of acute workload, represented as total distance accumulated over 7 days, compared to chronic workloads, calculated as the 4-week rolling average acute workload, was found to be predictive of injury in elite Rugby League. Specifically, when players were subjected to an acute 7-day workload that was classified as ~ twofold greater than the workload in which they were accustomed to, up to a 10-fold increase in injury occurred. During the in-season period in AFL players, Murray et. al. (173) reported that for the current week, a total distance chronic workload of > 20,000 m was associated with a lower risk of injury than a total distance workload of < 5,000 m (90%CI: 0.08-0.29, p=0.034). Additionally, players with an acute:chronic total distance workload of >2.0 were 5-8 times more likely to sustain an injury than players with an acute:chronic ratio of <0.49 (p=0.015) and between 0.5 and 0.909 (p=0.012) (173). Similarly, a 6-12 times greater injury risk was associated with a high-speed distance (18.01-24.00 $km \cdot h^{-1}$) acute:chronic ratio of >2.0 compared to ratios of <0.49 (p=0.006) and 1.0-1.49 (p=0.003). Piggott et. al (184) demonstrated acute spikes in weekly training load (>10%) accounted for ~40% of illness and injury in the subsequent 7-day period, while Colby et. al. (39) reported 3-weekly workloads to have the strongest relationship with intrinsic injury incidence in the pre-season and in-season period in Australian footballers. In the pre-season, 3-weekly total distances between 73,721 and 86,662 m were found to be associated with a greater injury risk when compared with <73,721 m (p=0.008). Although a 3-weekly sprint distance (>75% of individuals' maximum speed) between 864 and 1,453 m was shown to have a lower injury risk when compared with <864 m (p=0.045), a greater injury risk was associated with a 3-weekly sprint distance of >1,453 when compared to <864 m (p=0.07) (39). These data highlight the diverse applications of GPS and IA technology for the programming of training loads throughout the competitive season in contact team sport athletes. The prudent management of practice and training loads, to balance those associated with competition, is an ever-present challenge for sport coaches and performance staff. A paucity of research exists (56) on the positional movement demands of American football, however, data from similar contact team sports may provide a contextual framework for the use of GPS in American football.

The integration of IA provides scope to measure the frequency and magnitude of body movement in three dimensions, namely, anterior-posterior, mediolateral, and vertical (143). A unique measure referred to as 'player load' or 'body load' can be generated by GPS software (GPSports, Canberra, Australia, and Catapult Innovations, Melbourne, Australia). Player load (PL) is a calculation of the accumulated load based off magnitude of accelerations in three vectors, sampled at 100 Hz (242). Because acceleration is proportional to force, this measure may be useful when determining total load applied to a player in training and competition (242). The advantage of implementing this metric in contact sport is its ability to measure non-running activities such as kicking and jumping, along with impacts in tackles and collisions that commonly occur in contact team sports (242). Additionally, PL (Catapult Innovations, Melbourne, Australia) has demonstrated a nearly perfect correlation (r=0.94-0.97) with distance covered (7) (81), suggesting that PL may be an effective alternative to measure locomotive load in the absence of GPS availability, such as when a training session must be conducted indoors. Boyd et. al. (23) quantified external load in Australian football training and competition using accelerometers. The results of the study (23) demonstrated the capacity of GPS units with IA to differentiate between training drills and competitive games, and discriminate between players competing in elite and sub-elite team-sport competitions. Specifically, elite midfielders had higher a match PL (16.03% ± 4.21) than elite nomadics (14.96% ± 2.35), elite ruckmen (14.91% ± 3.30) and elite deeps (11.01% ± 2.63). Sub-elite midfielders (15.07% ± 2.02), nomadics (13.03% ± 2.36), and ruckmen (12.78% ± 5.49) displayed lower match PL than their elite counterparts (23). When Boyd et. al. (23)

compared match and training PL of elite players, only small sided games (15.52% ± 4.95) and match practice (midfielders 15.34% ± 2.84, nomadics 14.30% ± 2.89, deeps 11.68% ± 3.34, ruckmen 10.62% ± 2.57) were able to equal or exceed total loads for most positions. For elite deeps, small sided games greatly exceeded match PL, while match practice had much lower PL for ruckmen than matches. Boyd and colleagues (24) have demonstrated the intra-unit (0.91-1.05 % coefficient of variation [CV] and inter-unit (1.02-1.10 % CV) reliability of PL and determined its inter-unit reliability in Australian rules Football matches (1.90% CV). Managing training loads to mitigate injury risk is an on-going challenge for coaches and performance training staff. During the in-season period in Australian footballers, a three weekly PL of > 5,397 AU was associated with 2.5 times greater injury risk when compared with < 4,561 AU (p=0.031) (39). Young et. al. (242) examined the association between markers of muscle damage and GPS and accelerometer variables describing movements in Australian rules football. Player load was significantly (p<0.05) greater for the group who demonstrated high creatine kinase levels 24 hours post-match. Elevated creatine kinase levels were attributed to muscle damage induced by accelerometer derived high-intensity running with changes of direction, along with high acceleration and deceleration movements (242). Both acute and longitudinal load monitoring may be utilised to identify injury risk in collision based team sports, and subsequent exercise workloads can be modified to mitigate fatigue, establish recovery protocols, and improve competitive performance.

The physical demands of contact sports such as Rugby League (73, 154, 158), Rugby Union (50, 131), and American football (105, 142) are increased due to the large number of collisions that occur during training and competition (77). In sports associated with repeated high-intensity collisions and blunt force trauma indicative of American football, accelerometers offer a valid tool for detecting the frequency and magnitude of collisions (109) (73, 24). Using video recordings as the criterion measure, Gabbett et. al. (73) examined the validity of tri-axial accelerometers to detect collisions in Rugby League training. The number and intensity of collisions, and the incidence of collision injuries were monitored in 117 skills training sessions during the pre-season and in-season period, with the magnitude of each collision categorised as mild, moderate, or heavy. A strong correlation (r = 0.96, p<0.01) was demonstrated between collisions recorded by the accelerometers and those coded from video recordings. Across all three magnitudes, relationships between the criterion measure and the accelerometer detection method were high, indicating accelerometers offer a valid method for quantifying the contact load of collision sport athletes (73). Hulin et. al. (109) examined 380 video coded collision events, which occurred during Australian Rugby League competition, to investigate the sensitivity and specificity of the Catapult Sports S5 GPS units to accurately identify these occurrences. Researchers (109) reported the collision events identified by microtechnology units demonstrated a strong positive correlation with video coded collision events ($r=0.96$, 95% CI, 0.79-0.99). Gastin et. al. (85) quantified the frequency, velocity, and impact acceleration during tackling in Australian football. Using video footage as the criterion measure, differences were observed in accelerometer data between tackles of different intensities. High-intensity tackles were greater in speed of movement at contact and in the impact acceleration that resulted, compared to lower intensity tackles. Significant ($p<0.01$) differences were observed between low-, medium-, and high-intensity tackles in peak velocity and peak impact acceleration. Gastin et. al. (85) suggested GPS units with IA offer a valid method of quantifying tackles that occur in elite Australian football.

The capacity to monitor the contact load of athletes in collision sports, demonstrates the utility of tri-axial accelerometers (73). Monitoring the cumulative contact load on a weekly, monthly, or game by game basis, may provide coaches and medical staff with objective data to identify injury trends and risks associated with collisions in American football and other contact sports (131). There is currently a paucity of research investigating the positional-specific PL associated with practice and games in NCAA division I football. An examination of the GPS and IA-derived PL associated with pre-season and in-season practice and competition may help inform recovery strategies for players and improve specificity of training, resulting in optimal competitive performance.

#### 2.2.4 GPS Analysis in College Football

There is an absence of information that describes the physiological demands and movement patterns of practice and competition in NCAA division I college football players, with limited published research presented (56). DeMartini (56) evaluated the physical demands of NCAA division I college football players during nine preseason practices, using GPS units on 49 athletes. Global positioning system data were recorded throughout the entirety of each practice to evaluate total distance covered, distance covered in five distinct velocity zones, along with average and maximal heart rate. Participants were assessed as two broad groups, namely linemen vs. non-linemen and starters vs. nonstarters. The main finding was that non-linemen covered significantly ($p<0.05$) more distance and achieved higher velocities than linemen. Specifically, total distance covered for non-linemen was 3,532±943 m compared to 2,573±489 m for linemen ($p<0.001$) (56). In addition, non-linemen covered significantly greater distance in position drills (1,673±420 m vs. 1,231±189 m, $p<0.001$) and team drills (1,262±626 m vs. 915±83 m, $p=0.026$), respectively, compared with linemen. Total distance was significantly ($p=0.018$) higher in team drills for starters compared to non-starters (1,222±508 m vs. 850±525 m). No significant differences were found during position drills or total practice time for starters and non-starters. Regarding velocity measures, non-linemen covered a significantly ($p<0.001$) higher percentage of distance travelled in zone 4 (12.1–16.0 $km \cdot h^{-1}$) for practice drills, team drills, and total practice time than linemen did. In addition, non-linemen covered a significantly ($p<0.001$) higher percentage of distance travelled in zone 5 (>16 $km \cdot h^{-1}$) for position drills, team drills, and total practice time than linemen did. Conversely, linemen spent a significantly ($p<0.05$) higher percentage of distance covered in zone 1 (0–1.0 $km \cdot h^{-1}$) for position drills and total practice time and in zone 2 (1.1–6.0 $km \cdot h^{-1}$) for practice drills, team drills and total practice time. No significant differences were reported in percentage of distance covered for starters and non-starters for any of the velocity zones during any segment of practice (56).

A more recent investigation of the GPS-derived movement demands associated with participation in American football, examined the physical demands of an off-season high school scrimmage (88). Gleason et. al (88) divided Twenty-five athletes into two broad positional groupings, linemen and non-linemen, to assess the movement demands of a high-school scrimmage and to examine the influence of playing position on these demands.

Assessed movement profile variables included total distance, distance covered in six pre-defined velocity zones, and counts of total accelerations and decelerations in three predefined zones of intensity (88). Researchers reported significantly ($p<0.01$) greater total, running (14.5-19.8 $km \cdot h^{-1}$), striding (19.9-25.2 $km \cdot h^{-1}$), sprint (>25.2 $km \cdot h^{-1}$), and high-speed running (>14.4) distance for non-linemen versus linemen (88). No significant differences were report between groups for the number of acceleration or deceleration efforts performed. The broad positional groupings, limited number of observations, and level of competition associated with the investigation by Gleason et. al (88), provide limited information for football coaches and sports performance practitioners at the NCAA division I level.

Comparing the results of Gleason et. al. (88) with those of Demartini et. al. (56) is problematic due to the competitive level of the participants in each study, and the utilization of differing velocity zones. Total distance covered by non-linemen in each study (3532 ± 943 m vs. 3111 ± 891 m) was similar, however college linemen covered substantially greater distances (2,573±489 m) than their high school counterparts (1686 ± 302 m). The zones of intensity utilized in the two examinations were dissimilar, and as such, a comparison of the distance covered in each velocity zone cannot be made. Currently, the position-specific physical demands associated with pre-season practice, and in-season practice and competition in NCAA division I football players are poorly understood. A more detailed assessment of position-specific movement demands of NCAA division I football players will provide novel insight for an improved understanding of the demands of practice and competition, and enable increased scope for position-specific training and conditioning programs to optimize on-field performance.

## 2.3 Athlete Monitoring Strategies

### 2.3.1 Monitoring the Training Response

A judicious athlete monitoring system involves not only objectively quantifying the volume, intensity, and duration of physical activity completed, but also assessing the relative physiological and psychological response of this training (97). This training response is highly individual, and may be influenced by several factors including age, gender, training history, current training status, psychological factors, the ability to tolerate stress, and stressors outside of training (20). Previous research in contact team sport, with competitive demands indicative of NCAA division I football, has examined potential measures of an athlete's training response, including perceived wellness (72, 83, 153, 230), and the biochemical (16, 62, 153, 216, 230), neuromuscular (150, 154, 230), and heart rate variability (HRV) (60) response to training and competition, however ambiguity exists as to the methods that may be most pertinent to quantify this response (97).

#### 2.3.1.1 Heart Rate Variability

Advancements in sporting performance may be attributed to an increase in the cumulative volume of training loads, improved specificity of training protocols, and development of non-traditional methods of training (1). Optimal programming of and monitoring of training loads requires integration and interpretation of all variables, which may affect physical performance, including a combination of physiological and psychological attributes. Currently, technological limitations exist which make the measuring of all physiological systems during recovery from exercise problematic (214). Heart rate variability, a non-invasive measurement of the variation in the R-R intervals on an ECG (19), is a reliable reflection of many physiological factors modulating the normal rhythm of the heart (1). The simplicity of HRV measurement, and the information obtained on an athlete's recovery status, indicate frequent HRV assessments may aid in individualising training programs (138, 214).

The typical variability in heart rate (HR) results from autonomic neural regulation of the heart and circulatory system (206). The complementary actions of the sympathetic nervous system (SNS) and parasympathetic nervous system (PNS) branches of the autonomic nervous system (ANS) serve to regulate heart rate. Increased SNS or decreased PNS activity results in cardio-acceleration, while diminished SNS activity or heightened PNS activity results in cardio-deceleration (206). The balance between these systems affects the variation in consecutive time intervals between peaks of the QRS complex called the R-R interval, which can be measured by calculating HRV (151). Consequently, the degree of variability of HR provides insight into the functioning of nervous control of HR, and a valuable tool to investigate the sympathetic and parasympathetic control of the ANS (214).

A balanced level of activity of the SNS and PNS may result in better training adaptability and as a consequence, improved sports performance (38), whereas an imbalance between the branches of the ANS, or chronically reduced activity of either the SNS or PNS, may potentially result in performance decrements (6). Following exercise, changes in cardiac autonomic function offer a global marker of the body's homeostatic state, indirectly reflecting an individual's recovery status and readiness to undergo subsequent physical training (102). Heart rate variability has been demonstrated to be positively influenced by training, in particular endurance training, which results in an increase in HRV and PNS activity, as well as an accompanying decreased HR (6). Furthermore, HRV analysis may play an important role in predicting reductions in performance attributed to imbalances between training load and recovery, often characterised by an impaired autonomic balance (6).

Frequency-domain, time domain, and Poincaré plot parameters have commonly been used for assessment of the ANS (151). Frequency-domain analysis characterises high and low frequency rates of the variability changes, which correspond to sympathetic and parasympathetic activity. Low frequency (LF) modulation (0.04 – 0.15 Hz) of R-R interval changes correspond to SNS and PNS activity together, while HF modulation (0.15 – 0.4 Hz) is primarily regulated by innervation of the heart through the parasympathetic nerve (151). Time-domain parameters represent the standard deviation (SDNN) of all N-N intervals, reflecting the total variability and the root mean square of standard deviations (RMSSD) between adjacent N-N intervals, denoting parasympathetic activity (151). The N-N interval corresponds to the R-R interval of normal sinus beats. Poincaré plot analysis involve R-R intervals being plotted over time, with standard deviations being used to interpret changes observed on the plot, reflecting sympathetic and parasympathetic contributions (151). Measurement of HRV has become increasingly accessible, with technologies incorporated into standard HR monitors and smart phone applications, and thus, the practicality of HRV measures in applied settings has improved. In high-performance settings, the most pragmatic HRV index may be the natural log of the square root of the mean of the squares of the difference between adjacent R-R intervals (Ln rMSSD) (187), which requires a 10-60 second measurement (28).

While the utility of HRV measures in monitoring the training of endurance athletes (14, 58, 139, 183) has been documented, similar investigations in contact team sport athletes (60) are scarce. Pichot et. al. (183) assessed ANS activity using HRV in middle distance runners during a typical training cycle composed of three weeks of heavy training, followed by a relative rest week. Autonomic changes occurred following three weeks of intensive training in middle distance runners, characterised by a significant ($p<0.05$) and progressive decrease (up to 41%) in the HF and normalized HF (HFnu) parameters representative of parasympathetic drive. Following a recovery week, parasympathetic indices measured significantly ($p<0.05$) increased (46%), while indices of sympathetic (LF and LFnu) activity followed the opposite trend (183). These results suggest that alterations in autonomic balance accompanying intense exercise can be measured in a non-invasive manner by assessing HRV (58), although accounting for individual responses to training stimuli remains a fundamental difficulty with using HRV to examine changes associated with heavy physical exertion (58). Quantifying physical exertion relative to training volume and intensity may be a more logical way of analyzing this relationship between the effects of exercise on HRV. Earnest et. al. (58) examined the relationship between objective levels of exertion via training impulse (TRIMPS), resting HR, and HRV in eight professional cyclists during a three week stage race. Athletes who accumulated the most physical exertion during racing also showed the largest decrement in HRV, suggesting changes in HRV are directly related to exercise load, or volume and intensity of exercise (58). In contrast to research (58) indicating links between HRV and exercise loads, Hedelin et. al (103) reported HRV findings in nine canoeists involved in a six day training camp, corresponding to a 50% increase in training load. During the training camp, time to exhaustion, $VO_2$ Max, and maximal lactate decreased, however, no changes in HRV were found at rest.

Despite different training modalities, elite athletes have very similar time and frequency-domain HRV profiles (14). Berkoff et. al. (14) assessed autonomic tone via HRV in 145 Olympic athletes, grouped according to training emphasis, including endurance-trained and power-trained, prior to the 2004 U.S.A Olympic trials (14). The only significant ($p<0.05$) difference in autonomic tone reported was between male to female athletes, while training schedule showed no significant effects (14). Berkoff et. al. (14) concluded that elite endurance and power athletes have very similar time and frequency-domain HRV profiles. Utilising HRV analysis, practitioners gain valuable information regarding training response, recovery, and readiness for subsequent training across several sports including weightlifting (36) swimming (5), and elite endurance athletes (146).

In contact team sport similar to American football, Edmonds et. al. (60) examined the influence of weekly training, including competition, on time-domain, frequency-domain, and non-linear measures of HRV in nine elite youth Rugby League players, between the ages 17-20. All players participated in training sessions an average of five to seven times per week which included technical skills, resistance exercise, and aerobic conditioning, for an average of 52 ± 2 minutes per session. In addition, players participated in a regular mid-season premiership competition game consisting of two 40-minute halves. Training load and R-R intervals were recorded two days prior to the match (Pre-2), on match day, two consecutive days after the match (Post-1 and Post-2), and four days following the match (Post-4). The day following match-play, the percentage of consecutive normal-normal R-R intervals greater than 50 ms (pNN50) was significantly ($p<0.05$) lower than Pre-2, while all other time-domain HRV measures were similar over the monitoring period (60). Both absolute and normalised HF were significantly ($p<0.05$) reduced on match day and remained low until Post-2, in contrast to normalised LF and LF/HF which were increased on match day and remained elevated until Post-2 (60). The supine-to-standing change for absolute LF, normalised LF, normalised HF, and LF/HF was significantly ($p<0.05$) smaller on Post-1 compared to Pre-2, and remained smaller for Post-2 and Post-4 (60). Results demonstrated a shift in autonomic balance towards lower HRV on match day and a reduced HRV with predominant sympathetic modulations for 24-48 hrs post-match. Players exhibited a reduced ability of the ANS to respond to orthostatic stress, induced by supine-to-standing measures, for up to four days post-match. These results indicate a depressed cardiac sympathetic state associated with Rugby League competition, which may impact subsequent training and performance (60).

While the HRV response to American football practice and competition is largely unknown, data from individual and team sport athletes provide performance staff members a backdrop from which HRV monitoring may be implemented. The data obtained via the monitoring of day-to-day variations in HRV may provide additional scope for coaches seeking to optimise performance in high-intensity contact team sports. Cardiac autonomic regulation varies, and may be sensitive to stimuli from a variety of external and internal sources, particularly for athletes who are engaged in various daily training sessions, and are exposed to stressors that are extraneous to participation in their distinct sport (37) (205). Consequently, HRV measures must be interpreted in the context of the training phase, load, and distribution, as well as the training history of the athlete (28).

#### 2.3.1.2 Biochemical Measures

A variety of biochemical markers have been used in attempt to examine potential muscle damage in collision-based team sport athletes following competition. Indirect markers of skeletal muscle damage, including plasma creatine kinase (CK), have commonly been utilized to evaluate tissue disruption (105, 142, 158). Elevations in CK are indicative of increased skeletal muscle membrane permeability and have been associated with damage to skeletal muscle tissue, either from blunt force trauma resulting from collisions (158, 222) or repetitive eccentric damage during high-speed running throughout competition (121, 230). In Rugby League, McLellan et. al. (158) reported elevated CK levels for up to 120 hours post-competition, when compared to pre-competition CK levels. In comparison to 30 minutes pre-competition, significant ($p<0.05$) increases in CK were reported 30 minutes, and 24, 48, 72, 96 and 120 hours post-match. The results of McLellan et. al. (158) are consistent with those of Roe et. al. (201) who reported substantial increases in CK immediately following and 24, 48, and 72 hours post-competition in Rugby Union players. Roe et. al. (201) did not collect blood samples outside of the 72 hour post-competition window, so a comparison CK levels at

96 and 120 hours post-competition, similar to McLellan et. al. (158) is problematic. The peak in CK found 24 hours post-match is in agreement with other investigations in Rugby Union and American football (142, 222). Research in American football has evaluated CK in response to a single game (105), throughout the course of an in-season week (142), and over the course of the in-season period (104). Hoffman et. al. (105) examined, among other factors, the CK response to a single collegiate football game by collecting blood samples 24 hours pre-game, 2.5 hours pre-game, and 15 min post-game, in both starters and non-participants. No significant changes were reported in CK levels with respect to time intervals between players and non-players. Investigations (158, 201, 222) in contact team sport have reported increased CK levels 24-48 hours following competition, and as such, the lack of significant findings by Hoffman et. al. (105) may be attributed to the lack of sampling outside of the immediate post-game window. Additionally, this investigation was conducted during the tenth game of the competitive season, allowing the players sufficient time to adapt to the repeated collision events occurring throughout the in-season period in college football, perhaps resulting in a blunted CK response (104). A separate study (142) in NCAA division I football players evaluated CK levels 24 hours pre-, 18-20 hours post-, 42-44 hours post-game in both players and non-players. Kraemer et. al. (142) reported significant ($p \leq 0.05$) elevations in CK (41%) 18-20 hours post-game in those who played, when compared to pre-game levels, however CK levels returned to baseline at 42-44 hours post-game. Comparing the results Kraemer et. al. (142) with those from Hoffman et. al. (104) is problematic due to differences in the time-course of sample collection. A singular study (104) has examined the CK response of college football players throughout the course of the entire pre-season and in-season period. Researchers (104) obtained blood samples from starters and non-starters one day prior to pre-season training camp, at the end of pre-season camp, and during weeks three, seven, and eleven of the competitive season. Significant ($p < 0.05$) elevations in CK at the end of pre-season camp were reported in both starters and non-starters, with starters demonstrating significantly ($p < 0.05$) greater levels than non-starters, when compared to baseline levels (104). Creatine kinase concentrations returned to baseline levels by week 3 of the regular season, and remained at baseline levels throughout the rest of the season in both groups. Investigators (104) attributed this initial elevation of CK, followed by a prolonged return to baseline levels, to a potential ‘contact adaptation’ whereby skeletal

muscles become accustomed to the repeated trauma associated with collision and impact, resulting in a diminished CK response.

The use of biochemical markers as a means of quantifying the recovery and adaptive response of NCAA college football players, to the demands of practice and competition, appears to be of little benefit to the athlete and practitioner, and presents logistical concerns within the applied setting. The strict sampling procedures, the need for frequent collections, and the invasive nature of hematological measures, prohibit the use of biochemical markers within the athlete monitoring program (97).

#### 2.3.1.3 Neuromuscular Measures

Elite athletes are involved in substantial volumes of intense training in order to perform at a high level. Given the rigorous demands of elite level training, athletes are in a perpetual cycle of training-fatigue-recovery-adaptation, with athletes often training in the fatigued state (69). Neuromuscular performance decrements are often multifaceted in nature, and can stem from neural, contractile, and metabolic pathways (17). Fatigue monitoring in team sports such as American football is critically important, particularly during the competitive season where games are played on a weekly basis. Individual and group success depends largely upon maintaining the neuromuscular measures of strength and power (71) and mitigating the fatiguing effects of the preceding competition.

Neuromuscular fatigue (NMF) has been characterised as being task dependent, with mechanisms, which contribute to fatigue, varying according to the task the muscle performs, and no single mechanism accounting for the diminution in muscular force production (65). Typically, the mechanisms associated with NMF are classified as peripheral fatigue, occurring at or distal to the neuromuscular junction, and central fatigue, resulting from progressive failure to activate motoneurons during exercise (84). The central component of NMF represents a failure between the motor cortex and somatic nervous system to activate maximal muscle contraction and is referred to as a progressive, exercise-induced reduction in voluntary activation or neural drive to the muscle (224). The occurrence of central fatigue is largely demonstrated by an increase in the increment of force evoked by nerve stimulation techniques during maximal voluntary effort (224). An increase in the increment of force indicates central processes proximal to the site of the motor axon stimulation are contributing to a force decrement (223). Although the mechanisms that underlie central fatigue are complex, and it is difficult to specify all the sites within the CNS where contributions to voluntary action, central fatigue, and supraspinal fatigue occur (84), a decrease in motor unit firing rates has been demonstrated in sustained and repeated maximal efforts (15, 223). The mechanisms that contribute to the slowing of motor unit firing rates may be caused by a decrease in excitatory input, an increase in inhibitory input, or a decrease in the responsiveness of the motoneurons, with all three likely to occur during prolonged fatiguing activities (223) similar to American football competitions (219).

Exercise-induced NMF may also occur due to peripheral mechanisms, characterised as a reduction in muscular force production occurring at, or distal to the neuromuscular junction, referred to as peripheral fatigue (224). The contribution of peripheral fatigue to the reduction of voluntary muscle contraction is measured by the alteration in mechanical response of the muscle cells elicited by electrical or magnetic stimulation of the motoneurons that were active during exercise (70). Peripheral fatigue may result from failure at one or more locations in the periphery including the neuromuscular junction, propagation of the action potential along the muscle membrane and into the transverse tubule system, $Ca^{2+}$ release from the sarcoplasmic reticulum, $Ca^{2+}$ binding to troponin C, actin-myosin interactions during cross-bridge cycling, and active uptake of $Ca^{2+}$ by the sarcoplasmic reticulum $Ca^{2+}$-ATPase pump (65, 68).

Peripheral fatigue can be further divided into low frequency fatigue (LFF) and high frequency fatigue (HFF) (218). Low frequency fatigue is multifactorial fatigue resulting from high-intensity, moderate to high force, repetitive eccentric or stretch-shortening cycle (SSC) activities (69, 217). This form of peripheral fatigue is characterised by a proportionately greater loss of muscular force in response to low- versus high-frequency muscle stimulation. The recovery from LFF is prolonged, taking hours or days, with effects persisting in the absence of gross metabolic or electrical disturbance of the muscle (119, 125). It has been suggested that LFF may be caused by muscle fiber damage, typically the result of eccentric exercise or blunt force trauma associated with contact sport similar to American football (157), or impairment in the excitation-contraction coupling mechanism of muscle activation (119). Impairments in excitation-contraction coupling have been associated with decreases in the calcium sensitivity of troponin (120), poor conduction of the action potential in the T tubules (61), a reduction of $Ca^{2+}$ release from the sarcoplasmic reticulum (61, 120), and reduced $Ca^{2+}$ reuptake by the sarcoplasmic reticulum (13). Consequently, LFF may result in the need for higher levels of CNS activation, resulting in an increased sense of exertion during exercise (125). High frequency fatigue is characterised by a reduction in the force-generating capability of the skeletal muscle at high frequencies of stimulation, which is reversed by reducing the frequency of stimulation (16). This force decrement is accompanied by a loss of amplitude, a slowing of the waveform of the muscle action potential, and is exacerbated if extracellular [$Na^+$] is decreased or extracellular [$K^+$] is increased (16). Increases in extracellular [$K^+$] may result in decreased action potential propagation into the t-tubules, resulting in a reduced activation of the contractile elements involved in the generation of force (119).

Ideally, determination of NMF would be measured directly, utilising a maximal test of the athlete's specific sporting requirement (225), however several problems are associated with approach, namely, integrating a monitoring approach requiring repeated maximal testing would likely contribute to a fatiguing effect, which is illogical, particularly during the in-season period. In addition to the aforementioned limitations associated with sport-specific maximal testing, accurately defining which maximal performance test replicates a specific field sport, such as college football, is difficult (225). Isometric measures, which often involve a subject performing a maximum voluntary contraction (MVC) of a muscle group at a fixed joint angle for two to five seconds (31), have been popular laboratory based methods for evaluation neuromuscular function (186) (233). However, the true nature of neuromuscular function for sports performance is difficult to assess based upon isolated forms of isometric contractions that may not be representative of force development and NMF in American football players (140). Furthermore, the natural variation of muscle function during sports performance more often involves the SSC, and accordingly, provides a basis from which to study both normal and fatigued muscle. Stretch-shortening actions associated with performance of the counter-movement jump (CMJ) have been proposed as a method of assessment to measure LFF caused by excitation-contraction coupling impairments resulting from fatiguing exercise (69). Moreover, recognising the critical role dynamic strength and power play in the success of contact sport athletes (11), and American football players specifically (71), researchers have widely used CMJ assessments as the standard to measure sports performance and neuromuscular fatigue (105, 154, 157, 203). Functional performance assessments such as countermovement jump tests, maximal strength testing, and sprints may be utilised to gain an understanding of an athlete's physiological capacities. Therefore, in team-sports settings similar to American football, such as Rugby League and Union (154, 157, 237) and Australian rules football (ARF) (40, 41), testing that includes CMJ used to monitor NMF is commonly utilised as an indirect marker of maximal sports performance.

Performance of the CMJ by an individual is influenced by several factors including the peak force (PF) developed by the musculature involved, peak power (PP) , peak rate of force development (PRFD) (105), the timing and sequencing of segmental actions (107), the speed and amplitude of the countermovement (21), and the coupling time between eccentric and concentric phases (136). Fundamental differences exist between the CMJ and the squat jump (SJ), including the inclusion or exclusion of arm swing and lower limb countermovement during execution of the jump (98). The SJ typically involves subjects lowering themselves to a self-selected depth and maintaining that position for a brief period thereby eliminating any SSC contribution to the subsequent jump. During a CMJ, a preparatory eccentric countermovement of the lower limbs is performed prior to the concentric phase of the jump (105). An investigation (99) on the effect of arm swing and countermovement during vertical jumping examined the effect of VJ that involved no arm swing and no countermovement, no arm swing and countermovement, arm swing and no countermovement, and arm swing with countermovement, on jump height and velocity of the center of mass on a force plate. Both countermovement and arm swing significantly ($p<0.05$) increased jump height, while arm swing also resulted in higher peak vertical ground reaction forces and PP when compared to VJ with no arm movement or lower body countermovement.  It has been documented that CMJ results in higher VJ performances than SJ (18).  The mechanisms by which concentric force is enhanced may be explained by neural responses occurring during the rapid stretch that contribute to force improvements (57) or that the stretch of the series elastic elements causes storage of elastic energy, which is then reutilised during the propulsion phase (66). Based on the premise that during the CMJ, the active state, indicated by the fraction of actin binding sites available for cross-bridge formation, can be developed during the preparatory countermovement, but in SJ, the active state inevitably develops during the propulsion phase, Bobbert and Casius (18) utilised a human skeletal model to investigate whether the difference in jump height between CMJ and SJ could be explained by a difference in active state during propulsion.  Simulations were performed with a model of the human musculoskeletal system comprising four body segments and six muscles, which was stimulated to produce a maximum CMJ height.  The configuration at the lowest height of center of gravity from the CMJ was selected and utilised as the static starting configuration for simulation of the SJ maximum height assessment.  Researchers (18) concluded that the model's hip extensor muscles could produce more force over the first 30% of the shortening range in the CMJ due to the increased active state when compared to SJ.  Greater jump height in the CMJ was attributed to the active state being developed during the preparatory countermovement in the CMJ, as opposed to being developed during the propulsion phase as observed in the SJ, resulting in a higher active state in the CMJ than the SJ (18).  As an assessment of fatigue associated with SSC activities characteristic of movement demands in American football, the CMJ may provide a more pertinent evaluation than the SJ, due to the involvement of the SSC accompanying the eccentric component.

Countermovement jump performance has been measured utilising vane jump and reach devices (46, 212), contact mats (32, 243), and force platforms (153, 157, 199, 203).  Based on research by Bosco et. al. (22) the similarities in NMF between a CMJ and running suggest that the assessment of CMJ performance may be a pertinent method for monitoring NMF in running-based sports.  Examinations monitoring neuromuscular recovery following running exercise have demonstrated significant ($p<0.05$) reductions in CMJ height following interval running (179) and CMJ peak force and RFD following prolonged running (89). Bosco et. al. (22) examined the treadmill running economy and the mechanical efficiency during two different series of jumps executed with and without a pre-stretch. The ratio between the efficiency of muscular work performed during pre-stretch jumps and the corresponding value calculated in no pre-stretch conditions demonstrated significant relationships with energy expenditure during treadmill running ($r=-0.66$, $p<0.01$). This suggests that the elastic behavior of leg extensor muscles is similar in running and jumping if the speeds of muscular contraction during eccentric and concentric work are of similar magnitudes (22). The pattern of decreased CMJ peak force following running exercise indicates impaired contractile unit function and provides some support for utilising CMJ measures following SSC exercise to monitor neuromuscular fatigue following prolonged exercise (149).

Understanding the rates of recovery following different SSC exercise volumes is critical for assisting coaches in the monitoring and periodisation of this type of intense activity. Cadore et. al. (32) investigated the effect of different volumes of plyometric exercise (100, 200, or 300 hurdle jumps) on strength, a SJ initiated with knee joint at 90º in the absence of a countermovement, depth jump (DJ) (30, 40, and 60 cm) performance, and acute hormone and lactate responses in rugby players. Strength and SJ performance was assessed immediately pre-, 5 minutes post-, 8 hours post-, and 24 hours post-exercise. Maximal isometric peak torque and RFD of the knee extension (KE) and knee flexion (KF) were obtained using an isokinetic dynamometer at an angular velocity of $90^{\circ}\cdot s^{-1}$, while jump height was determined using a flight-time calculation on an electronic contact mat. Significant ($p<0.001$) reductions in SJ and DJ performance were observed 24 hours after all jumping protocols, with no significant changes immediately after or 8 hours following protocols (32). Reductions ($p<0.02$) in peak torque were observed immediately after, 8 hours post-, and 24 hour post-exercise for all plyometric protocols (32). In addition, maximal RFD was decreased ($p<0.001$) immediately after, 8 hours post-, and 24 hour post-exercise for all plyometric protocols (32). Results (32) indicated that neuromuscular performance is negatively impacted 24 hours following plyometric training in rugby players, and suggest that coaches should carefully monitor the volume of plyometric training protocols. Plyometric exercise is an integral aspect of sports training and has demonstrated increases in strength (52), power

(42), jump height (52), and sprint performance (52), and therefore is often programmed into the training program of athletes who rely on the aforementioned qualities for sporting success, such as NCAA division I football players. Caution should be exercised when implementing plyometric exercise, particularly during the competitive season in American football, where intense SSC exercise may further contribute to reductions in neuromuscular power associated with NCAA football competition (105).

An examination of CMJ measures may provide insight into neuromuscular function, however the variables most sensitive to NMF remain ambiguous (225). Generally, investigations utilizing CMJ analysis as means of examining NMF associated with participation in contact team sport, have included the variables of PF, PP, PRFD (105, 154, 157), and flight time (40, 167, 230), however these variables alone may mask the sensitivity of alternative NMF measures (87).

McLellan and Lovell (154) utilized the CMJ to evaluate neuromuscular responses associated with Rugby League competition. When compared to pre-match values, significant ($p<0.05$) decreases in PRFD and PP were reported 30 minutes and 24 hours post-match, while reductions in PF were significant ($p<0.05$) 30 minutes post-, but returned to baseline levels 24 hours post-match (154). These results (154) are similar to those reported by McLellan et. al. (157) who reported significant decrements in PP, PRFD, and PF following Rugby League competition that returned to pre-match values within 48 hours post-match, and the results of McLean et. al. (153) and Twist et. al. (230) which demonstrated significantly reduced CMJ power and flight time measures for 48 and 24 hours, respectively, following Rugby League competition. However, other investigations examining PRFD, PP, and PF following competition in ARF (40) and American college football (105), found no significant difference between pre-competition and post-competition measures, suggesting that these force-power variables may be maintained in contact team sport athletes. Hoffman et. al. (105) examined CMJ measures throughout the course of an American college football game by evaluating PF and PP immediately prior to kickoff, and following the completion of the first, second, third, and fourth quarters of competition. No significant declines in PF of PP were reported from one measure to the next, however both PF and PP following the second quarter were 18% and 20% ($p<0.05$), respectively lower than pre-game values.  Both PF and PP measures returned to baseline levels by the completion of the game (105), suggesting a lack of diminution in force-power variables resulting from competition in American football, however comparing these results with previous research in contact team sport is problematic due to the lack of 24-, 48-, and 72-hour post-game testing.

Evaluating CMJ force-power characteristics requires the use of a force plate technology (87, 154, 157) and as such, may prohibit the evaluation of these characteristics in the applied setting.  A paucity of information exists (105) outlining neuromuscular changes associated with participation in American football, and as such, investigations from similar contact team sport (153, 154, 157) provide a structure from which performance staff may implement NMF fatigue monitoring strategies.  In the university athletic setting, time constraints associated with warm-up protocols (87) for CMJ testing, and the ambiguity surrounding appropriate testing variables (225) may prove problematic for frequent monitoring of athlete readiness.

#### 2.3.1.4 Athlete Self Report Measures

In effort to promote performance adaptations, successful training must involve overload, but must also avoid the chronic combination of excessive overload and inadequate recovery (163).  As an athlete's ability and training age increase, the mode, frequency, and intensity of the stimuli become increasingly important (193), with periods of increased training intensity commonly used by athletes for purposes of performance enhancement (163).  The avoidance of overtraining and the realisation of optimal performance are attained only if athletes are able to optimally balance training stress and subsequent recovery.  Insufficient recovery may initiate a process that results in an elevated stress state, which appears on a continuum of increased training load, possessing endpoints of no training and overtraining (129).  An acute period of intensified training and associated fatigue, followed by subsequent increases in performance, forms the basis of effective training programs (163) and emphasises the need for a valid and reliable tool to monitor athlete recovery status.  Identifying a practical means of monitoring the balance of fatigue and recovery is critically important in college football, which involves an intense pre-season practice period, followed by weekly competitions, and the associated practice and training sessions.  It is reasonable to expect that American football players, like other contact sport athletes, tolerate different levels of training, competition, and stress at different times, depending on their level of health and fitness throughout the season. The training load should therefore be individualised, with alterations based upon the athlete's response and adaptation to programmed loads (29).

In addition to training and competition in college football, stressors such as fear of failure, social and relational stress, and stress associated with maintaining academic standards, may affect an athlete's adaptive capacities to training and competition (127).  Individually, the athlete may adequately manage social, academic, relational, and competitive stressors, but collectively, the combination of the aforementioned stressors represent an accumulation of stress that may become overwhelming (130).  Athlete self-report measures (ASRM) are cost-effective and provide quick, actionable data when compared to common physiological monitoring practices, which may take hours or days to receive feedback (129, 210).  In a team sport setting with a substantial number of athletes, each possessing individual differences, receiving accurate and timely information regarding individual recovery status is paramount.

Taylor, et. al. (225) distributed an online survey to 100 individuals within the Australian and New Zealand high performance sporting sectors.  The purpose of the research was to gather information on the type of athlete monitoring systems considered current best practice.  Of the methods identified for monitoring fatigue responses to training and competition, self-report questionnaires were most common (84%) (225).  The type of self-report forms most commonly used were custom-designed forms (80%), followed by the Recovery-Stress Questionnaire for athletes (RESTQ-Sport) (128), Profile of Mood States (POMS) (161), and Daily Analysis of Life Demands for Athletes (DALDA) (204).  Results from Taylor et. al. (225) suggested brief, custom-designed forms were preferred to lengthier questionnaires existing within the scientific literature, due to the time required for completion, and the time constraints associated with the applied high-performance sporting environment.

Self-report questionnaires can provide simple and useful information for strength and conditioning coaches and performance specialists, however, the frequency of administration, the sensitivity of the questionnaire, the time of day the questionnaire is administered, and its length need to be considered to facilitate the implementation of subjective forms of player monitoring in an applied setting (97). The aim of monitoring training and recovery in college football players is to reach a balance where training yields the most favorable increases in performance. Terry et. al. (226) sought to determine which psychological variables are most responsive to physical training demand, which measures are most appropriate to measure training-induced fluctuations, and whether a dose-response relationship existed between training load and psychological response in 60 athletes from basketball, golf, hockey, and rowing over a training period of up to 16 weeks. Training weeks were grouped into high, high-moderate, moderate-low, and low training loads, and results of subsequent subjective monitoring indicated psychological responses showed a clear association between training load, under-recovery, stress responses, and mood disturbance. A dose-response relationship was demonstrated, whereby negative psychological indices progressively increased as the training load increased (226). Jürimäe et. al. (122) have confirmed dose-response relationships of training volume and subjective measures of stress and recovery in rowers who participated in four weeks of intensified training. Coutts and Reaburn (44) evaluated a self-report questionnaire to measures changes in stress and recovery during six weeks of either normal or intensified training in 20 Rugby League players. The intensified and normal training groups demonstrated significant ($p<0.05$) differences in the stress subscales of fatigue, general stress, and disturbed breaks (44). Studies in soccer players during the competitive season support the use of ASRM for assessing risk of overreaching (26) and as an indicator of athletes who may be at increased risk for illness (25). Additionally, Kalda et. al. (124) demonstrated the utility of a self-report measure as a predictor of competitive performance in sprinters and jumpers. Results indicated competition performance to be negatively associated with self-assessed fatigue, while better performances were associated with lower fatigue states (124).

The competitive season in college football generally consists of games played on a weekly basis. A Study by McLean et. al. (153) revealed perceptual levels of fatigue are increased the day following professional Rugby League competition but return to baseline levels by day four with appropriate training. McLean et. al. (153) further demonstrated that psychological markers including fatigue, sleep quality, general muscle soreness, stress levels, and mood coincided with a reduction in physiological performance measures including CMJ performance, which also returned to pre-match levels by day four. Together, the results of McLean et al (153) support the use of psychometric tools to assess recovery from training and matches in Rugby League. Research in AFL (165) has demonstrated perceptions of game-related soreness dissipate within three days following competition, and players that achieved higher running velocity and repeated high-intensity running efforts reported greater levels of muscle pain, resulting in a prolonged post-match recovery period (86). In Rugby Union players (94) the factors of playing position, level of experience, and playing status demonstrated significant ($p<0.05$) differences in recovery-stress balance and mood states. Specifically, forwards had more favorable mood scores than backline players, experienced players demonstrated the least favorable mood scores, and reserves showed more favorable mood score than starters (94). To assess individual training responses, Buchheit et. al. (27) examined the usefulness of monitoring daily variations of selected physiological and psychometric variables during a two-week pre-season Australian rules football camp. Wellness questionnaires assessing perceived fatigue, sleep quality, general muscle soreness, stress levels, and mood, were completed daily upon waking and reflected responses to the previous day's training load. Wellness scores were found to be stable throughout the course of the two-week pre-season camp that included ten outdoor skill sessions, seven interval cycling sessions, and eight indoor strength training sessions, however daily variations in training load were found to influence all wellness measures the following day, with higher training loads resulting in lower wellness scores. The pattern of daily variation over the course of a two-week pre-season training period as reported by Buchheit et al (27) highlights the meaningfulness of simple and practical methods to monitor fatigue, stress, and wellness in the team sport setting. An examination (72) of the time course of perceptual recovery following NCAA division I football games demonstrated less favorable ratings of perceived soreness and overall wellness that persisted for up to four days following competition. While the results of the study (72) shed new light on perceptions of wellness associated with NCAA division I football seasons, it did not examine perceived wellness the day following competition or quantify the game day movement demands associated with the wellness response. Collectively, previous studies (27, 44, 86, 94, 153) (165) support the use of subjective appraisals of recovery in individuals participating in contact team sports, however limited (72) investigations in American football have been reported. Examinations in American college football may yield insights into player management strategies aimed at mitigating excessive fatigue and improving the recovery-stress balance associated with training and competition.

While self-report questionnaires may be able to identify perceived changes in feelings of fatigue and wellness in team sport athletes (27, 86, 94, 153, 169), the ability of wellness measures to predict performance in elite level team sport athletes remains unknown. Gastin et. al. (86) examined how players were coping with the training and competition demands of elite level Australian football over the course of a competitive season using subjective ratings to monitor changes in physical and psychological wellness (86). The players completed ratings for nine wellness items, six of which were physical in nature, including fatigue, general muscle strain, hamstring strain, quadriceps strain, pain or stiffness, and power, while the remaining three were psychological in nature including sleep quality, stress, and well-being. Results from Gastin et. al. (86) demonstrated low values for all nine items measure throughout the course of the season, indicating that players generally coped well with the demands of in-season training and competition. The highest scores over the entire season, indicating a reduced ability to cope with demands, were associated with the items of sleep quality and pain or stiffness. Additionally, faster players had significantly ($p<0.001$) worse ratings for muscle strain, hamstring strain, quadriceps strain, and power following match-play, while older players experienced decreased sleep quality following match-play (86). The authors (86) suggest the significant ($p<0.05$) improvements in wellness scores following a week of reduced load further demonstrate the sensitivity of subjective measures to undulations in training and competition. Significant ($p<0.05$) but very weak negative correlations with performance were observed for general muscle strain ($r=-0.105$) and hamstring strain ($r=-0.110$) suggesting that performance is negatively impacted in players who reported higher, or worse scores on these items (86). The correlations between general muscle strain and hamstring strain and performance reported by Gastin et. al (86) may only account for 1-3% of the variance in player performance, however, the margin between winning and losing in elite sports is often equally small.  Gallo (80) examined the relationship between pre-training self-reported wellness, including sleep quality, fatigue, stress, mood, and soreness, and external load in Australian footballers.  Results demonstrated that a one unit decrease in wellness Z-score resulted in a 4.9% (95% CI: ±3.1) decrease in player load, and an 8.6% (95% CI: ±3.9) decrease in player load slow (<2.0 $m \cdot s^{-1}$).  These findings (80) suggest that a decrease in external load associated with training sessions may be preceded by lower ratings of pre-training subjective wellness, indicating alterations in training program may be appropriate to mitigate the risk of maladaptation.  Recently, the relationship between the pre-practice subjective wellness measures of soreness, sleep, and energy and external load (PL) in NCAA division I college football players was investigated (90).  Govus et. al. (90) reported a one unit increase in wellness Z score was associated with a trivial, 2.3% (90% CI: 0.5, 4.2), but significant (p=0.04) increase in PL, and a one unit increase in energy corresponding to a trivial 2.6% (90% CI: 0.1, 5.2) and insignificant (p=0.08) increase in PL.  The relationship between wellness Z score and PL suggests that higher pre-practice self-reported wellness may result in higher loads achieved subsequent training and practice sessions (90).

Self-report measures assess athlete's subjective, or perceived, well-being, and due to their practicality and cost-effectiveness, are often the preferred method for frequent monitoring.  Previous reports (27, 47, 97, 163) suggest ASRM may be more sensitive and reliable than traditional physiological, biochemical, and performance measures for athlete monitoring purposes.  In an applied setting, it has been suggested that ASRM be employed to enable early detection of athletes at risk for nonfunctional overreaching, overtraining, or staleness (26, 47, 129), with research supporting ASRM for identifying athletes at risk for illness (244) and injury (3, 79, 226).

Self-report measures are typically used to assess the impact of an acute training phase or intervention, such as a pre-season training camp in NCAA division I football, on athlete wellness, and have demonstrated sensitivity to training stress, exhibiting a dose-response relationship with training load (27, 190, 209).  Currently, a paucity of research (72, 90) exists characterizing the use of ASRM in NCAA division I football, and information detailing the effect of movement demands on subjective wellness measures is nonexistent.

### 2.3.2 Self-Report Measures of Perceived Wellness

#### 2.3.2.1 Profile of Mood States (POMS)

The POMS questionnaire, originally designed to monitor the moods of psychiatric outpatients, has evolved to for use in sport, contains 65 items yielding a global measure of mood (171). Individual measures of negative mood states including tension, depression, anger, fatigue and confusion, along with the positive mood state of vigor, are used to assess individual mood state responses to training loads. Morgan (172) indicated that athletes tend to score below the population average on the tension, depression, anger, fatigue and confusion scales of the POMS, while scoring above the population mean for vigor, creating an overall athlete profile referred to as the “iceberg profile” (172). The POMS questionnaire was used in a group of collegiate swimmers throughout a competitive season (171) and demonstrated that healthy profiles progressively deteriorated by mid-season during a period of intense training, however, when training stress was reduced, healthy POMS profiles were restored (171). The POMS has been identified as an effective tool for assessing psychological changes related to both single training sessions and changes associated with a three week training camp in elite kayakers (134). Using the POMS questionnaire, Horodyska et. al. (134) evaluated mood states of eleven elite kayakers involved in a three-week training camp, before and after selected workouts each week, to assess both training-induced mood disturbances and recovery following differing time periods. The energy index, comprised of changes in vigor and fatigue scores, gradually declined over the course of the three-week camp, indicating increased mood disturbance, but rebounded following planned recovery periods (134). Regular monitoring of psychological indices utilising the POMS may help detect training maladaptation, thereby mitigating fatigue and improving subsequent performance.

In order to obtain measures of mood state in a more time efficient manner, shortened versions of the 65-item POMS, including the 24-item Profile of Mood States-Adolescents

(POMS-A), have been developed and demonstrated validity as a measure of mood among adults (227).  Alternatively, the Brief Assessment of Mood (BAM) is a six-item measure of mood, designed as a brief version of the POMS, which assesses six mood states including anger, anxiety, confusion, depression, fatigue, and vigor on a five point scale, the sum of which yields a composite total mood disturbance score (54).  A large (n=621) validation study by Dean et. al. (54) reported acceptable correlations (r =.66-.87) between BAM Mood Disturbance Scores and the POMS Total Mood Disturbance Scores.  The POMS has been established as a valid measure and exhibited a dose-response relationship between training load and observed scores.  The recovery-stress state reveals the degree to which an individual is physically or mentally stressed as well as the capability for of the individual to utilise recovery strategies to normalize the physical and psychological state (126).  Kellman et. al. (126) suggested that although the POMS may provide an economical approach to examining and identifying changes on emotional state, it may be inadequate for examining and monitoring the individual recovery process in athletes (126).  Additional limitations of the POMS, including its intended use in clinical practice, which may lack specificity for athletes (163), and the substantial number of questions (65 items), may preclude its use to monitor individual recovery-stress states in NCAA division I college football players.

#### 2.3.2.2 Recovery-Stress Questionnaire for Athletes (REST-Q Sport)

The Recovery-Stress Questionnaire for Athletes (REST-Q Sport) is a 76-item questionnaire, which utilizes ten subscales to measures the frequency of stress, and nine subscales for measuring recovery associated activities (128). The REST-Q Sport questionnaire is employed in high-performance settings, to identify the degree to which athletes are physically or mentally stressed, and their current ability to recover (128).  Coutts and Reaburn (44) evaluated the efficacy of the RESTQ-Sport to measure changes in stress and recovery during six weeks of training followed by a seven-day taper period in 20 semiprofessional Rugby League players.  During the final week of training, players were separated into intensified training and normal training groups, resulting in 12.5 and 8.7 hours of physical training for the week, respectively.  The intensified training group demonstrated significantly ($p<0.05$) different scores from the normal training group on measures of fatigue, general stress, and disturbed breaks (44). Due to extensive nature of the REST-Q Sport, it may not be practical for daily assessments, but may be utilized over a four to six week period to adequately describe the responses of team sport athletes to training (44). The high test-retest reliability demonstrates the results of the RESTQ-Sport are stable for short-term fluctuations and changes of state and that inter-individual differences in the recovery-stress state can be reproduced (127). Decret et. al. (55) tested the psychometric properties of the RESTQ-Sport through confirmatory factor analyses and showed it to be a reliable and valid tool for estimating the recovery-stress state of athletes. Additionally, translations of the original English version have shown reliability and validity for use in individual and team sports (177). An examination (51) of 585 athletes training at a Canadian national sport center validated the sport specific scales for recovery and stress, but not the factor structure for general stress and recovery scales (51). In rowers, high training loads induced decreases in performance, increases in stress, and deteriorations in REST-Q Sport recovery values, in addition to suppressed central and peripheral steroid hormones (123, 215). A dose-response relationship between stress and training load, along with an inverse relationship between recovery and training load has been demonstrated in rowers (123, 188), triathletes (47), combat sport athletes (168), and team sport athletes (44, 67).

In NCAA division I football, periods of intensified physical training are implemented to physically stress the players at specific times in order to enhance physical fitness, such as during pre-season camp. Due to the high volume and intensity associated with pre-season camp, adequate recovery phases must be included within the schedule to systematically enhance performance (126). The RESTQ-Sport has been found to be effective in monitoring recovery and fatigue in individuals and groups during intensified training camps (127) (126). Assessments of the individual recovery-stress state may prove beneficial during performance plateaus to guide athletes and coaches in determining whether further increases or decreases in training volume and /or intensity would result in performance improvements. The REST-Q Sport provides acceptable test-retest reliability, and as such, players can be assessed up to 48 hours before competition, allowing coaches and performance managers adequate time to optimise the recovery-stress state (126).

### 2.3.2.3 Daily Analysis of Life Demands for Athletes (DALDA)

In team sport athletes, completion of the RESTQ-Sport has been reported to take approximately 10-12 minutes (137). Head coaches may not support allocating this amount of time to monitor the stress-recovery state of team sport athletes, consequently, more time-efficient monitoring tools such as the Daily Analysis of Life Demands for Athletes (DALDA) (204) may be preferred in high-performance applied environments (137). The DALDA is a 34-item questionnaire, developed as a sport-specific test to evaluate the presence of training and non-training stressors, in addition to symptoms of stress (204). Results of the DALDA can be used to determine the nature of an athlete's response to training and evaluate their capacity to tolerate training loads. The first part of the inventory, Part A, describes the general stress sources that occur in the everyday life of the athlete, while Part B is used to determine stress-reaction symptoms that may exist in the athlete (204). In applied settings, the DALDA is recommended as a daily or every other day assessment (204), however, the sensitivity of the questionnaire is not reduced if used on a weekly basis (200), and it appears to be robust enough to be used in research (144).

The DALDA was designed to assess changes within an athlete, rather than between athletes, over the course of a season. Therefore, baseline measures must be established for each individual, with changes in scores providing information regarding the stress response of the athlete. This tool has evolved after having the content validated, the readability checked, and the reliability established (204). The DALDA is an effective and practical method for monitoring fatigue and recovery in athletes, with the 'worse than normal' responses significantly increased with intensified training, and decreased following a taper (47). In cyclists, changes in mood state assessed by the DALDA occurred alongside performance decrements (96). In addition to the stressors associated with training and competition, the assessment of stressors unrelated to participation in sport is also relevant (178). Nicholls et. al. (178) examined the sources of sport and non-sport stress and their associated symptoms on rest days, training days, and match days in 16 male Rugby Union players completing the DALDA for 28 consecutive days. The results from Nicholls et. al. (178) suggested that professional Rugby Union players experienced more sport and non-sport stress on training days when compared to match or rest days, evidenced by training days eliciting significantly

($p<0.05$) “worse than normal” stress scores for diet, climate, sleep and health. On rest days, home-life, friends, and recreation sources of stress were rated as significantly “better than normal”, while diet, sports training, and health were rated as significantly ($p<0.05$) “worse than normal” (178). In addition to an increased understanding of the adaptive response of athletes provided by monitoring the stress response to training and competition in collision team sport (178), ‘worse than normal’ responses on the DALDA may precipitate negative immunological changes (169, 200). Robson-Ansely et. al. (200) demonstrated the DALDA was able to detect an increase in stress level prior to any immunological changes during intensified training in triathletes, supporting its use as an early warning system to the possible onset of overtraining (200). Additionally, Moreira et. al. (169) found the number of ‘worse than normal’ responses increased during intensified training, which coincided with a higher incidence of upper respiratory tract infections in basketball players.

Despite assessments of subjective questionnaires stress and recovery in athletes participating in several other individual (55, 123, 134, 171, 188) and team sports (44, 67), a paucity of information exists regarding self- report wellness in American football players. Prudent monitoring of training adaptations may allow applied performance practitioners to minimise performance decrements, particularly in NCAA division I football where competition occurs on a weekly basis. However, in applied high-performance settings, care must be taken to minimise the time burden on the athletes and avoid ‘questionnaire fatigue’, resulting in athletes responding in an unvarying or random manner (97, 163).

#### 2.3.2.4 Custom Questionnaires

There exist a small number of subjective questionnaires that have demonstrated accuracy in assessing athletes’ response to training and competition loads including the RESTQ-Sport (128), POMS (171), and DALDA (204) among others. Due to the comprehensive and time-consuming nature of the self-report questionnaires commonly used to monitor athletes’ perceived wellness, the practicality of their implementation presents considerable logistical challenges in a high-performance applied setting (228). A survey of the current trends in fatigue monitoring among Australian and New Zealand high-performance sport revealed that 84% of respondents used self-report questionnaires, 80% of which were custom designed forms consisting of 4-12 items (225). Consequently, it has been recommended that coaches and performance staff utilize brief, customized questionnaires, similar to the one employed by McLean et. al (153) within an athlete monitoring system (106).

An approach to athlete self-report measures recommended by Hooper and Mackinnon (106) is for questionnaires to include well-being ratings of fatigue, stress, sleep, muscle soreness, enjoyment of training, irritability, and health. Based largely upon these recommendations, custom-designed questionnaires have been utilized within collision-based team sport including Australian Football (27, 83, 86) Rugby League (116, 153, 230) and NCAA division I football (72) to examine perceptual wellness associated with training and competition. During the competition phase of the Australian football season, Gallo et. al. (83) utilised a customized self-report questionnaire to rate sleep quality, muscle soreness, stress, fatigue, and mood on a 7-point Likert scale. Days-to-game was the best predictor of perceived wellness, with one-day post-match wellness scores in an 8-day microcycle lower than one-day post-match scores in a 6- and 7-day microcycle (83). Similar findings were reported by Gastin et. al. (86) who demonstrated that days-to-game was a significant ($p<0.001$) coefficient for wellness in Australian footballers, highlighting the improvement in all wellness variables as competition approaches. Additionally, the customized self-report questionnaire was sensitive to daily and weekly fluctuations in recovery status, particularly with the increased loads associated with games, and load reductions resulting from bye weeks. Faster players reported significantly ($p<0.05$) worse ratings for muscle strain following competition, indicating increased recovery time for players with higher maximum running velocities (86). In Rugby League players, McLean et. al. (153) employed a customized form that assessed fatigue, sleep quality, general muscle soreness, stress levels, and mood on a 1-5 Likert scale, and demonstrated significantly ($p<0.01$) worse fatigue, soreness, and wellness scores the day following competition, regardless of the microcycle length. Overall well-being and general muscle soreness remained significantly ($p<0.05$) reduced two days post-match for the 7- and 9-day microcycles, compared to the 5-day microcycle, underscoring the importance of days-to-game as an indicator of perceptual wellness (153). Following Rugby League training and competition, significant ($p<0.05$) increases in perceived fatigue with simultaneous decreases in performance have been demonstrated (64, 153, 230).

Perceptions of fatigue often outlast reductions in performance, however improvements in both perceived fatigue and performance measures may improve following a period of reduced training (64).

Data characterising the self-reported wellness associated with participation in NCAA division I football are limited, and research (72) has only provided a rudimentary understanding of the perceived wellness during the in-season period. Fullagar et. al. (72) utilised a custom questionnaire to rate soreness, sleep quality, and energy levels on a 1-5 Likert scale, 1 day pre- and 2, 3, and 4 days post-game in NCAA division I football players. Additionally, an overall wellness score was derived from the average ratings of the three wellness scores. Standardized effect size analyses ± 90% confidence intervals were used to interpret the magnitude of the mean differences between all time-points. Compared to one day pre-game, soreness and energy levels were very likely and likely worse 4 days post-game, while overall wellness remained very likely worse four days following the game (d=0.20-0.59). These results suggest that pre-game wellness markers may take longer than 4 days to return to baseline levels following competition in NCAA division I football players (72). These data provide a basic assessment of the self-reported wellness over the course of an American college football season, yet do not identify specific movement variables that may be associated with the differential ratings of perceived wellness. Identifying the movement characteristics associated with increased or decreased fatigue, soreness, stress, mood, and sleep will provide sport scientists and coaches a platform from which to design and implement individualized training and recovery protocols to mitigate maladaptation and optimize performance.

### 2.3.3 Considerations for Athlete Monitoring

While endeavoring to improve performance, athletes will continue to push the physical boundaries of preparation as a means to enhance competitive performance. Consequently, an athlete monitoring system should be established which provides an increased degree of certainty for the prescription of training loads, for sport coaches and performance managers seeking to optimize training adaptations and subsequent performance, while mitigating the risk of maladaptation including overtraining, injury, and illness (97, 208). A myriad of training and non-training factors may influence performance outcomes and the well-being of an athlete. Identifying and quantifying each of these participating factors is problematic, however their cumulative influence may be monitored in terms of the training response (97). Implementation of an athlete monitoring system necessitates a time investment, and the allocation of financial and human resources to collect, analyze, and utilize the data effectively (208). An evaluation of the training response in athletes using self-report measures, such as subjective perceived wellness questionnaires, are practical, inexpensive, and may provide superior responsiveness over objective measures (209). Monitoring the training response using self-report measures represents an additional, albeit minimal, burden to the athlete, and to be sustainable, this burden must be minimised through ease of administration, the ability to be completed anywhere, and efficient output of results (97). According to Saw et. al. (207), a key determinant of the efficacy of implementation of a self-report measure is whether an athlete consistently uses it across an entire training period. To encourage consistent compliance, factors including athlete and staff buy-in, time burden, content, and outputs must be considered (208). Regarding social environmental factors that may influence compliance, athlete buy-in appears to be of critical importance (207), with team sport athletes rating buy-in of others higher than athletes participating in individual sports. Buy-in may be facilitated by educating the athletes as to why a self-report measure is to be used, the purpose of the questions, who sees the data, and how the data may be used for the benefit of the athlete (208). Buy-in by coaches and other influential personnel of the sports program is necessary to encourage initial use and provide feedback to provide impetus for buy-in amongst athletes (207).

Questionnaire fatigue, whereby athletes record similar responses despite actual perceptions, may be problematic with lengthy questionnaires or too frequent monitoring. Consequently, self-report measures must be time efficient and short enough to retain athlete engagement, yet thorough enough to yield valid data (208). In applied, high performance sport settings, custom questionnaires typically include 4-12 items measured on Likert point scales ranging from either 1-5 or 1-10 (225). Although many customized questionnaires may lack empirical validation, they provide valid information, rendering scientific confirmation unnecessary (225). For ongoing data collection, there is a paucity of research to suggest an ideal frequency, however administering self-report measures 2-3 times a week may be infrequent enough to avoid questionnaire fatigue, yet often enough to identify acute trends within the training response (208). The effort needed and the time burden required for athletes to complete a self-report measure are vitally important for sustained use, and therefore a measure should seek to maximize interest and minimize burden to gain initial and continual compliance (207).

While player buy-in and time demands required for completion of ASRM are critical factors concerning compliance, the content of an ASRM is vitally important, particularly for self-directed athletes. Research (207) has indicated that self-directed athletes want a measure which could be customized to accommodate data which they felt was relevant to the preparatory process, including their specific sport, interests, and intended purpose. Avoiding the burden of seemingly irrelevant data was also important to self-directed athletes, however the individual customization of self-report measures may disrupt the data continuity and applicability, and as such, careful consideration must be taken prior to customization in a team setting (207).

The data gleaned from self-report measures must present perceptible value to the athlete in order for sustained use (208), however concerns over who has access to this data, how it may be perceived by coaches, and the implications associated with the data, have been expressed amongst athletes (207). Athlete concerns over data privileges and interpretation of results may be mitigated through targeted and efficient coach to athlete communication, thereby creating awareness in team-sport athletes that the coaches are interested in the data and consider it meaningful (210). Based on responses of Australian athletes (210) a lack of feedback from the coaches resulted in athletes seeing limited return for their effort, ultimately resulting in a loss of interest in completing the measure. Additionally, athletes wanted feedback in a timely manner, and sought clear interpretation, rather than a re-presenting of the data (210).

The ultimate objective of an ASRM is to mitigate the risk of undesired outcomes including injury, illness, and overtraining and to enhance competitive performance. To this end, daily training prescription may be altered in response to ASRM data in efforts to continually provide high levels of stress to the athletes, while simultaneously avoiding maladaptation (210). Howver, subjective self-report assessments are not without potential problems. As previously reported (163), mood state may be influenced by stressors unrelated to training and recovery. Additionally, psychological measures can be biased or rendered invalid by various forms of faking and response distortion. Response distortion involves athletes “faking good” to present themselves in a more positive light, or “faking bad” to have training load reduced (163). Athletes are more likely to engage in “faking good” if they are anxious about non-selection, afraid of presenting themselves as mentally weak, or are concerned about the privacy of their data (63, 211). Self-report measures are intended to act as an alert system, which identify potential issues and allow sport coaches and performance managers to take a proactive approach to individualize training prescription. Software has enabled automatic alerts to be programmed and sent to the coaching staff in response to concerning data, however the criteria for what constitutes a concern is varied (210). In applied sport settings, thresholds such as 5% below the mean value or one standard deviation from the mean have been reported (225). Consistent, longitudinal data collection over an in-season period is intended to reveal trends in athlete responses, from which performance managers and coaches can obtain insight into the acute and chronic response to training and competition, and ultimately gain an increased understanding of individual load tolerance.

### 2.4 Summary

Despite the popularity of American football, the scientific investigation of the physiological demands and subsequent psychological responses associated with pre-season and in-season practice and competition has been neglected. A previous examination (56) of the movement demands associated with pre-season training camp NCAA division I football players provided rudimentary insight into the physical demands of only a limited number of practice sessions. Similarly a limited amount of data (72) exists characterizing the perceived wellness associated with participation in NCAA division I football, and consequently, the psychological response associated with the specific physical demands remains unknown. Due to the paucity of research in American football, current athlete preparation strategies are based predominantly on tradition and anecdotal evidence. The focus of the present research therefore, is to quantify the position-specific movement demands characterizing pre-season and in-season practice and competition, and to provide insight into the perceived wellness, utilizing a custom questionnaire, associated with these demands.

The dearth of scientific data available on the position-specific physical demands of NCAA division I football may be attributed to the late adoption of GPS technology within applied high-performance athletic programs in the United States. Additionally, the disproportionate reliance upon past experience of successful coaches as a means to drive training protocols, may result in the scientific process being undervalued, and as such, player and staff buy-in becomes problematic. The present research was successfully completed at two separate exclusive division I college football programs, both of which rank in the top ten in all-time wins, with unprecedented access to elite players preparing for NCAA division I football competition.

In elite athletes, support exists for the use of self-report measures to evaluate risk of overreaching (26), as an indicator of individuals who may be at increased risk for illness (25), and as a predictor of competitive performance (124). Additionally, a dose response relationship between training load and perceived wellness has been established in collision-based team sport athletes (27, 153, 165), however the perceived wellness associated with practice and competition loads in NCAA division I football players is unknown. Accordingly, a greater understanding of the physical movement demands, and the subsequent perceived wellness responses to pre-season and in-season practice and competition, may provide increased scope for individualized training and regeneration strategies, mitigate the risk of maladaptation, and optimize competitive performance.

# Chapter 3

## Quantification of Competitive Game Demands of NCAA Division I College Football Players Using Global Positioning Systems

### 3.1 Introduction

American football is a field-based team sport requiring high levels of muscular strength, power, speed and agility, and is characterised by intense collisions and repeated high-intensity movements (196). American football games are intermittent in nature involving short-duration high-intensity bouts of exercise, which incorporate movements such as sprinting, backpedaling, accelerating, decelerating, and physical collisions, separated by transient periods of low-intensity recovery between plays (111). During the in-season period of competition, players competing in NCAA division I college football are required to participate in twelve regular season games on a consecutive weekly basis. Few studies have investigated (111, 194) the demands of NCAA division I football games and as such, the movement characteristics of competition in college football players remain ambiguous. While research (111, 194) has provided a rudimentary description of exercise to rest ratios encountered during NCAA division I college football games, a more detailed assessment of position-specific movement demands during competition provides novel insight to improve our understanding of the demands of competition and enable increased scope for position-specific training and conditioning programs to optimize on-field performance.

The development of global positioning system (GPS) technology with integrated tri-axial accelerometers (IA) have allowed the physiological demands of training and competition in contact team sport to be quantified by tracking the movement of players (9, 74, 242). Improvements in GPS technology have subsequently resulted in enhancements in accuracy (115), and the validity and reliability of GPS to determine the movement demands of team sports is well established (45, 117, 118, 231). The quantification of team-sport competition demands using GPS technology has been reported in sports similar in nature to American football, including Rugby League (9, 74, 160), Rugby Sevens (92), Australian football league (AFL) (148, 221, 240), and Rugby Union (50, 156). Further substantiating the use of GPS technology to accurately determine position-specific demands of team sport, Boyd et. al. (23) demonstrated the capacity of GPS units with IA to differentiate between training drills and competitive games, and discriminate between players competing in elite and sub-elite team-sport competitions. Although GPS technology is widely used in team sports for analysis of game and training movement demands, current literature on the movement profile characteristics of American football players is limited (56).

DeMartini et. al. (56) reported movement profile characteristics associated with pre-season training sessions in NCAA division I college football by examining the physical demands of division I college football players during nine pre-season practices over the course of eight days, utilizing GPS to evaluate total distance covered and running velocity characteristics. The main findings reported by DeMartini et. al. (56) were that non-linemen covered greater total distance and sprint distance than linemen, who covered greater distance at slower speeds. To date, ambiguity remains regarding the demands of in-season NCAA Division I college football games and team training activities (56).

In American football each position group has distinct physiologic and biomechanical demands associated with specific technical and tactical requirements (141), however uncertainty exists regarding the position-specific movement demands of NCAA football competition. Given the widespread inclusion of GPS technology in collegiate American football programs, a detailed assessment of competitive movement profile characteristics will provide sports performance specialists with quantified information on game demands. A more comprehensive understanding of the demands of NCAA football competition will augment our understanding of the position-specific movement demands of NCAA college football players, and allow sport coaches to individualize training programs that replicate the demands of American football games.

The aim of the present study was to 1) examine the competitive physiological movement demands of NCAA division I college football players using portable GPS technology during games, and 2) to examine positional groups within offensive and defensive teams, to determine if a player's physiological requirements during games are influenced by playing position. We hypothesized that there will be substantial positional differences in movement demands of NCAA division I college football players during games. Data obtained will provide scope for performance coaches seeking to optimize position-specific training regimens.

## 3.2 Methods

### 3.2.1 Experimental Approach to the Problem

Portable GPS and IA technology was used in the present study to quantify the position-specific movement characteristics of NCAA division I college football games. The GPS movement profile data was collected during twelve regular season NCAA division I college football games. All games were 60-minutes in duration, comprised of four 15-minute quarters, each followed by a brief recovery period, and played outdoors between the hours of 12:00 and 21:00 over a period of twelve to thirteen weeks from September to November. All participants were required to participate in a minimum of 75% of the total offensive or defensive plays for the GPS datasets to be included in the present study. Each individual GPS dataset was characterized as constituting either offensive or defensive team performance, and subsequently divided into specific positional groups for the offense that included wide receivers (WR), quarterbacks (QB), running backs (RB), tight ends (TE), offensive linemen (OL), and for the defense that included defensive backs (DB), linebackers (LB), defensive ends (DE) and defensive tackles (DT).

### 3.2.2 Subjects

Thirty-three NCAA division I Football Bowl Subdivision (FBS) football players (age 20.7 ± 1.0 years; height 188.6 ± 7.2 cm; and mass 106.7 ± 19.6 kg) participated in the present study. The heights and mass for each position group are expressed as means ± standard deviation and presented in Table 3. All subjects were collegiate athletes whom had been selected to participate in the football program eight months prior to the commencement of the study. All participants in the present study took part in the teams' off-season physical development training program that included a full-body strength and power training program and specific skills and conditioning sessions designed to simulate the demands of NCAA division I college football competition. The present study comprises statistical analysis of data collected as part of the day to day student athlete monitoring and testing procedures within the university's football program. Researchers were provided with de-identified GPS datasets from twelve regular season games for analysis. De-identified data included participant playing position for the purposes of position-specific data analysis. Ethical approval was obtained from the the university's human research ethics committee (RO-1929).

**Table 3.** Study 1, position group heights and mass expressed as means ± standard deviation.

| Position Group Heights and Weights | | |
|---|---|---|
| **Position** | **Height (cm)** | **Mass (kg)** |
| **Defensive Tackle** | 191.0 ± 0.4 | 135.2 ± 0.3 |
| **Defensive End** | 193.4 ± 3.6 | 118.6 ± 5.8 |
| **Linebacker** | 186.3 ± 3.4 | 105.5 ± 2.5 |
| **Defensive Back** | 182.8 ± 5.2 | 86.4 ± 6.1 |
| **Offensive Line** | 196.8 ± 3.9 | 136.8 ± 5.0 |
| **Tight End** | 196.6 ± 1.1 | 115.0 ± 7.1 |
| **Running Back** | 181.8 ± 2.0 | 97.8 ± 10.3 |
| **Quarterback** | 192.4 ± 2.3 | 93.0 ± 1.6 |
| **Wide Receiver** | 185.6 ± 10.5 | 91.3 ± 12.4 |

### 3.2.3 Procedures

### 3.2.4 Global Positioning System Units

The present study used commercially available GPS receivers (SPI HPU, GPSports, Canberra, Australia) which operated in a non-differential mode at a sampling frequency of 15 Hz. The GPS receivers also contain IA, which operated at 100 Hz and assessed the frequency and magnitude of full-body acceleration ($m \cdot s^{-2}$) in three dimensions, namely, anterior-posterior, mediolateral, and vertical (143, 158). Subjects had previously worn GPS receivers in outdoor training sessions that included football-specific running and skill-related and game-simulated contact activities during a three week pre-season training period. Prior to the commencement of each game, GPS receivers were placed outside for 15 minutes to acquire a satellite signal, after which, receivers were placed in a custom designed pocket attached to the shoulder pads of the subjects. Shoulder pads were custom-fit for each individual, thereby minimizing movement of the pads during competition. The GPS receivers used in the present study (66 g; 74 mm x 42 mm x 16 mm) were positioned in the center of the upper back, slightly superior to the scapulae. Subjects were outfitted with the same GPS receiver for each of the twelve games. Following the completion of games, GPS receivers were removed from the shoulder pads, and subsequently downloaded to a computer for analysis utilizing commercially available software (Team AMS, GPSports, Canberra, Australia). The validity and reliability of GPS to measure distance and velocity during high-intensity exercise that characterizes contact and noncontact team sports have been reported (12, 59, 117, 181). Johnston et. al. (117) have demonstrated GPS receivers utilized in the present study to be valid for measuring total distance and average peak speed in a team sport simulation circuit, with intraclass correlation values of interunit reliability reported to be 0.94 for high speed running (14.00 – 19.99 $km \cdot h^{-1}$) distance, 0.81 for very high speed running (> 20.00 $km \cdot h^{-1}$) distance, - 0.20 for total distance, and – 0.14 for peak speed.

Data provided from GPS receivers were assessed as movement profile variables including total, low-intensity, moderate-intensity, high-intensity and sprint distances (m), maximal velocity achieved ($km \cdot h^{-1}$), and counts of sprint, acceleration and deceleration efforts. Classifications of parameters of movement profile variables are described below and presented in Table 4. Each of the GPS variables measured in the present study was calculated using commercially available software (Team AMS, GPSports, Canberra, Australia).

### 3.2.5 Movement Classification System

Movement profile classifications have been described for game analysis in similar contact team sports (154, 155, 159, 160), however the classification profile utilized in the present study was devised for American football players. Each movement classification was coded as one of four speeds of locomotion (Table 4). Low-intensity movements, such as standing, walking and light jogging, were considered to be 0 - 10 $km \cdot h^{-1}$, moderate-intensity movements, such as a cruising jog, were considered to be 10.1 – 16.0 $km \cdot h^{-1}$, high-intensity movements, such as fast jog or striding, were classified as 16.1 – 23.0 $km \cdot h^{-1}$, and sprinting or maximal effort movements were classified as exceeding 23.0 $km \cdot h^{-1}$. Short duration high-intensity movement efforts, or measures of acceleration and deceleration, were classified as three groups, specifically, moderate (1.5 – 2.5 $m \cdot s^{-2}$), high (2.6 – 3.5 $m \cdot s^{-2}$) and maximal (> 3.5 $m \cdot s^{-2}$) and presented as a count of how many efforts an athlete undertook per game.

**Table 4.** Movement Classification System

| **Speed of Locomotion** | |
|---|---|
| **$km \cdot h^{-1}$** | **Movement Classification** |
| 0 – 10 $km \cdot h^{-1}$ | Low-Intensity |
| 10.1 – 16 $km \cdot h^{-1}$ | Moderate-Intensity |
| 16.1 – 23 $km \cdot h^{-1}$ | High-Intensity |
| > 23.0 $km \cdot h^{-1}$ | Sprinting/Maximal Effort |
| **Acceleration and Deceleration** | |
| **$m \cdot s^{-2}$** | **Movement Classification** |
| 1.5 – 2.5 $m \cdot s^{-2}$ | Moderate |
| 2.6 – 3.5 $m \cdot s^{-2}$ | High |
| > 3.5 $m \cdot s^{-2}$ | Maximal |

### 3.2.6 Statistical Analyses

All movement and variables from the present study were presented as descriptive statistics, mean ± standard deviation (SD). Hypothesis testing was conducted to determine any main effects for movement profile data between position groups on the offensive and defensive teams. A one-way ANOVA was used to determine positional group main effects. In the event homogeneity of variance assumption was violated, a Welch Robust Test of Equality was used to determine main effects between position groups. For all main effects detected by a one-way ANOVA, post-hoc Bonferroni tests were utilized. Alpha intervals for all hypothesis testing were set at $p<0.05$ as the level of significance for statistical tests. All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS for Windows, version 14.0; SPSS, Inc., Chicago, IL. USA).

## 3.3 Results

### 3.3.1 Offense

Significant ($p<0.001$) main effects from ANOVA testing were reported for all movement profile variables measured in the present study for the offensive position groups (Table 5). Post-hoc analysis of movement profile variables revealed total distance, moderate-intensity distance, high-intensity distance and sprinting distance covered by the WR position was significantly ($p<0.001$) greater in comparison to all other offensive position groups, including RB, QB, TE, and OL. Low-intensity distance covered by the WR position was also significantly ($p<0.001$) greater for all offensive position groups apart from QB. The QB position group covered significantly ($p<0.001$) more low-intensity distance than RB, TE, and OL positions. Moderate-intensity distances were significantly ($p<0.05$) greater for RB and QB position groups compared to TE and OL position groups. High-intensity distances were significantly ($p<0.01$) greater for the RB and TE positions compared to QB and OL positions. Sprinting distances were significantly ($p<0.001$) greater for RB compared to OL. The average maximal speed achieved by WR, RB and QB positions was significantly ($p<0.05$) greater than TE and OL positions, while the average maximal speed achieved by WR position group was significantly ($p<0.05$) greater than the RB position group.

For all high-intensity movement profile variables, including sprint efforts, moderate-, high-intensity, maximal-intensity acceleration and deceleration efforts, the WR position was involved in significantly ($p<0.01$) more efforts than any other offensive position group. The QB and RB positions were involved in significantly ($p<0.01$) more sprint efforts per game compared to TE and OL positions. The TE and OL groups were involved in significantly ($p<0.001$) more moderate acceleration efforts than the RB and QB positions; however, the OL position group had significantly ($p<0.001$) less maximal acceleration efforts compared to QB and RB positions. The OL position was also involved in significantly ($p<0.001$) more moderate deceleration efforts compared to the RB position, while for maximal deceleration efforts, the OL position was involved in significantly ($p<0.05$) less than the RB and QB position groups.

**Table 5.** Offense positional movement profiles. Data are means ± standard deviations. [W]Significantly different (p<0.05) for WR. [R] Significantly difference (p<0.05) to RB. [Q] Significantly difference (p<0.05) to QB. [T] Significantly difference (p<0.05) to TE

| Movement Variables | Wide Receiver (WR) | Running Back (RB) | Quarter Back (QB) | Tight Ends (TE) | Offensive Linemen (OL) |
|---|---|---|---|---|---|
| **Running Zone Distances** | | | | | |
| **Total Distance (m)** | 6048.2 ± 1089.8 | 3434.6 ± 749.7 W | 4103.1 ± 876.9 W | 3908.7 ± 964.7 W | 3940.1 ± 422.1 W |
| **Low Intensity Distance (m)** | 3546.2 ± 756.2 | 2291.3 ± 482.0 W | 3661.5 ± 642.2 R | 2579.2 ± 663.8 W Q | 2885.4 ± 663.8 W R Q |
| **Moderate Intensity Distance (m)** | 1530.9 ± 341.2 | 738.4 ± 247.2 W | 568.3 ± 147.8 W | 947.2 ± 155.5 W R Q | 913.2 ± 147.8 W R Q |
| **High Intensity Distance (m)** | 655.2 ± 196.3 | 303.1 ± 118.7 W | 138.1 ± 65.1 W R | 336.5 ± 137.8 W Q | 131.1 ± 65.7 W R T |
| **Sprinting Distance (m)** | 315.8 ± 163.2 | 101.2 ± 71.7 W | 76.9 ± 46.0 W | 40.3 ± 47.4 W | 9.3 ± 11.3 W R |
| **Average Max Speed ($km \cdot h^{-1}$)** | 31.5 ± 2.2 | 28.8 ± 2.5 W | 29.4 ± 8.5 | 25.3 ± 7.8 W R Q | 23.7 ± 2.8 W R Q |
| **High Intensity Movement Efforts** | | | | | |
| **Sprint Efforts (#)** | 12.7 ± 5.7 | 4.6 ± 3.1 W | 2.8 ± 1.9 W | 1.5 ± 1.6 W R | 0.3 ± 0.5 W R |
| **Moderate Acceleration Efforts (#)** | 62.2 ± 14.0 | 26.3 ± 11.2 W | 26.8 ± 9.1 W | 49.0 ± 19.7 W R Q | 46.7 ± 13.5 W R Q |
| **High Intensity Acceleration Efforts (#)** | 38.2 ± 13.1 | 18.7 ± 7.7 W | 21.0 ± 7.8 W | 21.5 ± 14.3 W | 16.5 ± 5.9 W |
| **Maximal Acceleration Efforts (#)** | 21.9 ± 8.1 | 8.2 ± 4.9 W | 9.3 ± 5.9 W | 5.5 ± 4.1 W | 1.5 ± 1.6 W R Q |
| **Moderate Deceleration Efforts (#)** | 36.9 ± 14.0 | 15.6 ± 7.2 W | 22.2 ± 7.5 W | 22.0 ± 8.5 W | 25.1 ± 7.1 W R |
| **High Intensity Deceleration Efforts (#)** | 18.5 ± 13.1 | 7.9 ± 7.7 W | 9.7 ± 7.8 W | 9.3 ± 14.3 W | 8.3 ± 5.9 W |
| **Maximal Deceleration Efforts (#)** | 15.8 ± 5.4 | 6.4 ± 3.5 W | 6.3 ± 3.4 W | 4.7 ± 3.9 W | 2.6 ± 2.0 W R Q |

### 3.3.2 Defense

Significant (p<0.001) main effects from ANOVA testing were reported for all movement profile variables measured in the present study for defensive position groups team (Table 6). Post-hoc analysis of movement profile variables including total distance, moderate-intensity distance, high-intensity distance and sprinting distance covered, revealed that both the DB and LB positions covered significantly (p<0.05) greater distances in all zones than the DE and DT positions during games. The only main effect reported for distance covered between the DB and LB position groups was for low-intensity distance covered, with the DB position covering significantly (p<0 .05) more than the LB position group. The DB position had the highest average maximal speed which was significantly (p<0.05) greater than all other defensive positions. The average maximal speed of the LB position group was significantly (p<0.05) greater than DE and DT positions, although significantly (p<0.05) less than DB. The DE position average maximal speed was significantly (p<0.05) greater than the DT position, and significantly (p<0.05) less than DB and LB positions.

The DB position group was involved in significantly (p<0.05) more sprint efforts, moderate-, high-, and maximal-intensity acceleration and deceleration efforts, than the DE and DT positions groups. Apart from moderate acceleration and deceleration efforts and high-intensity deceleration efforts, the DB position group was involved in significantly (p<0.05) more high-intensity movements than the LB position group. The LB position group was involved in significantly (p<0.05) more sprint efforts, high- and maximal-intensity acceleration and deceleration efforts than the DE and DT positions. Lastly, the DE position group was involved in significantly (p<0.05) more high-intensity acceleration efforts than the DT position group.

**Table 6.** Defense positional movement profiles. Data are means ± standard deviations. [B]Significantly different ($p<0.05$) for DB. [D] Significantly difference ($p<0.05$) to DT. [E]Significantly difference ($p<0.05$) to DE.

| | Defensive Backs (DB) | Defensive Tackles (DT) | Defensive Ends (DE) | Line Backers (LB) |
|---|---|---|---|---|
| **Running Zone Distances** | | | | |
| **Total Distance (m)** | 5127.6 ± 1209.5 | 3295.0 ± 711.7 B | 3549.0 ± 883.4 B | 4533.5 ± 1072.1 D E |
| **Low Intensity Distance (m)** | 3448.7 ± 923.0 | 2499.5 ± 456.9 B | 2662.8 ± 652.5 B | 2989.1 ± 721.5 B D E |
| **Moderate Intensity Distance (m)** | 926.1 ± 247.4 | 629.0 ± 249.0 B | 665.2 ± 224.0 B | 912.5 ± 271.4 D E |
| **High Intensity Distance (m)** | 513.8 ± 155.5 | 158.6 ± 62.0 B | 226.0 ± 96.1 B | 435.0 ± 165.0 D E |
| **Sprinting Distance (m)** | 247.0 ± 113.1 | 7.7 ± 10.9 B | 29.2 ± 24.1 B | 196.7 ± 104.7 D E |
| **Average Max Speed ($km \cdot h^{-1}$)** | 31.1 ± 1.9 | 23.5 ± 1.7 B | 26.1 ± 2.6 B D | 29.6 ± 1.2 B D E |
| **High Intensity Movement Efforts** | | | | |
| **Sprint Efforts (#)** | 10.6 ± 4.3 | 0.4 ± 0.6 B | 1.4 ± 1.4 B | 8.0 ± 4.1 B D E |
| **Moderate Acceleration Efforts (#)** | 45.1 ± 16.0 | 29.5 ± 9.9 B | 31.9 ± 11.2 B | 37.1 ± 14.4 |
| **High Intensity Acceleration Efforts (#)** | 32.2 ± 11.4 | 15.4 ± 5.7 B | 20.0 ± 6.8 B | 26.4 ± 11.0 B D E |
| **Maximal Acceleration Efforts (#)** | 20.9 ± 8.6 | 2.8 ± 2.2 B | 7.2 ± 4.6 B | 13.1 ± 6.2 B D E |
| **Moderate Deceleration Efforts (#)** | 29.5 ± 11.5 | 19.5 ± 7.5 B | 22.7 ± 9.4 B | 23.7 ± 11.0 |
| **High Intensity Deceleration Efforts (#)** | 19.4 ± 11.4 | 7.9 ± 5.7 B | 10.6 ± 6.8 B | 14.3 ± 11.0 B D |
| **Maximal Deceleration Efforts (#)** | 14.0 ± 6.1 | 2.6 ± 2.0 B | 5.4 ± 2.9 B | 10.4 ± 5.1 B D E |

### 3.4 Discussion

The present study examined the competitive physiological movement demands of NCAA division I college football players using portable GPS technology during games, and assessed positional groups within offensive and defensive teams, to determine if a player's physiological requirements during games are influenced by playing position. The results of the present study provide novel insight into the competitive demands experienced by NCAA division I college football players, and provide scope for the design of position-specific and game-specific physical conditioning strategies for coaches seeking to optimize training for the demands of competition. The results confirm our hypothesis that significant differences in movement profiles accompanying NCAA division I college football games exist between playing positions. The most notable finding for physical characteristics of games in both offensive and defensive teams were the movement profiles of the WR, DB, and LB positions, with athletes in these three position groups covering more total distance at higher intensities compared to all other positions on their respective offensive and defensive teams.

The total distance covered by athletes in team-sport competition such as American football, may be considered an overall reflection of running volume. The present study found a significant ($p<0.001$) difference in total distance traveled between position groups within both the offensive and defensive teams. The WR position group covered more total distance per game than all other offensive groups. Similarly on defense, the DB and LB position groups covered greater total distance than the DT and DE position groups. The finding of the present study that the WR, DB, and LB position groups covered greater total distance is consistent with the work of DeMartini et. al. (56) that found significant differences in distance traveled between linemen (2573 ± 489 m) and non-lineman (3532 ± 943 m) during pre-season training. However, the present study evaluated game data over the course of twelve games compared to DeMartini et. al. (56) who evaluated data obtained during pre-season training in the heat. The absence of published research in relation to the demands of NCAA division I football games make comparisons with others problematic. Despite the absence of comparable studies, the present results indicate that the total distance covered for both linemen (3314.0 m) and non-linemen (4141.3 m) during games are greater than those data reported by DeMartini et. al. (56). From an observational perspective, results from the present study may be attributed to the increased distance from the line of scrimmage from which the WR, DB and LB position groups started plays. Beginning play further from the line of scrimmage gives athletes a larger area for movement, providing an increased movement requirements during plays and further distances to travel between plays to huddle for brief tactical discussion related to subsequent play. Given WR, DB and LB covered greater total running distance throughout games than their offensive and defensive teammates, it is reasonable to suggest athletes in these positions may require modified running volumes in training to support recovery and adequately prepare them for the physical demands of subsequent competition.

In addition to differences in total distance covered by WR, DB, and LB, the present study found significant ($p<0.05$) differences in moderate-intensity, high-intensity, and sprint distances covered by WR, DB, and LB compared to all other positions on their respective teams. The RB and TE covered significantly ($p<0.05$) more high-intensity distance than OL. Similar observations in American football training were made by Demartini et. al. (56) who reported non-linemen covering significantly ($p<0.001$) more high-intensity ($>16.0$ km·h$^{-1}$) distance for position drills, team drills, and total practice time than linemen in pre-season training. Positional differences observed in the present study may be attributed to the position-specific requirements of games. Tactically, the primary responsibility of OL is to block defensive players, preventing opponents from tackling their own team's ball carrier. These movements are associated with short bursts of acceleration, deceleration, and change of direction, which most frequently occur within a few yards of the line of scrimmage, thereby limiting the distance traveled per play. Players in the DT and DE position groups characteristically accelerate short distances and perform rapid change of direction movements before engaging the opposing OL, followed by pursuing the ball carrier. The position-specific requirements of the OL, DT, and DE positions, requiring a static play initiation posture at or near the line of scrimmage at commencement of each play followed by contact with an opponent positioned approximately one meter apart, likely influences subsequent running distances. These distances are less than that covered by other positions on the offensive and defensive teams that require players to travel greater distances prior to engaging an opponent. The differences in high-intensity distance covered by TE and RB, compared to OL, may be attributed to the more diverse requirements of these position groups, including blocking, running with the ball, and releasing on pass routes. The WR position group is required to repeatedly run passing routes at high velocities throughout the course of games, consequently accounting for significantly greater high-intensity distance and significantly more sprint efforts when compared to all other offensive positions. The DB position group is primarily responsible for defending WR on passing routes, however they also provide secondary support on running plays. As the last line of defense, the DB position is often responsible to make tackles on long running or passing plays, which is indicated in the current study with greater high-intensity distance and more sprint efforts of DB when compared to all other defensive positions.

In addition to the distance covered during play, the WR and DB cover more distance between plays as they are required to jog back to the line of scrimmage at the conclusion of plays, which may be a distance 20-30 m to either huddle or re-assume their alignment for subsequent play, whereas OL, DT, and DE characteristically walk short distances during recovery between plays (194). The LB position is required to defend running plays in addition to covering WR, RB and TE on passing plays, which may account for similar movement characteristics to the DB position. The results of the present study highlight the unique movement demands of WR, DB and LB position groups in comparison to other positions on their respective offensive and defensive teams, and is potentially related to their proximity to the line of scrimmage at the initiation of play. Young et. al. (242) reported greater running distance covered at high speed, along with moderate and high accelerations and decelerations to be associated with markers of muscle damage in collision team-sport players, and consequently, the monitoring and prudent adjustment of weekly training loads specifically for the WR, DB and LB positon groups, may reduce the likelihood of subsequent performance decrements associated with fatigue.

Research (8, 156, 160) in team-sports utilizing portable GPS technology indicate positional differences in movement characteristics during competition. No previous studies have reported the movement demands of NCAA division I football competition, consequently a lack of understanding exists regarding the demands of American football games. Investigations in team sports similar to American football, including Rugby League, Rugby Union, and Australian rules football, indicate significant differences exist in high-intensity movements including acceleration and deceleration efforts (213, 242), and maximal speed (33, 160) between position groups. The present study found significant differences in maximal running speeds and maximal acceleration and deceleration efforts recorded from offensive position groups. The average maximal speed of WR position was significantly ($p<0.05$) greater than all other offensive positions except QB. The RB and QB position groups average maximal speed was significantly ($p<0.05$) greater than that of both the TE and OL position groups. The WR group had significantly ($p<0.05$) more sprint, maximal acceleration, and maximal deceleration efforts than all other offensive position groups, presumably do to repeated route running requiring sprinting and frequent changes of direction.

Defensively, there were no significant differences between total, moderate-, or high-intensity distance covered between DB and LB position groups, however, significant ($p<0.05$) differences were indicated for average maximal speed, sprint, maximal acceleration, and maximal deceleration efforts. The DB group had significantly ($p<0.05$) more sprint, maximal acceleration, and maximal deceleration efforts than all other defensive positions, highlighting the specific high-intensity running requirements of this position during defensive play. The LB position group demonstrated significantly ($p<0.05$) greater average maximal speeds, sprint, maximal acceleration, and maximal deceleration efforts than the DE and DT groups. Similar research (56) has not quantified high-intensity movement characteristics of individual position groups, making comparisons with the present study difficult.

The significant differences between the DB group when compared to the defense as a whole, and the LB compared to DT and DE, highlight three distinct running profiles for the defensive team, requiring different forms of training to achieve optimal development. The starting positions upon commencement of each play for the DB and LB groups afford larger areas to achieve higher maximal speeds, while the positional requirements of defending pass routes and pursuing ball carriers result in greater changes of direction for the DB and LB groups. The WR and DB position groups achieved significantly greater maximal speeds, sprint efforts, and maximal acceleration and deceleration efforts than their respective offensive and defensive counterparts throughout the course of games, indicating the need for positional specificity in speed training for NCAA division I football players.

The results of the present study provide novel insight into position-specific physical demands of NCAA division I football games and provide physical performance staff with quantified information, which can potentially be used to replicate the physical demands of games in training. The present study demonstrated appreciable differences in the positional movement demands of NCAA division I college football games, emphasizing the need for position-specific training to adequately prepare players for the rigors of competition.

### 3.5 Practical Applications

The present study provided a novel analysis of the movement demands associated with NCAA division I college football games. The results indicated significant differences in total running volume and high-intensity movement demands, most notably for the WR, DB, and LB position groups. Higher overall running loads were experienced for these three position groups, while greater high-intensity movement demands were required of the WR and DB groups. Data from the present study augments our understanding of the competitive demands experienced by NCAA division I college football players, and provides scope for the design of position-specific and game-specific physical conditioning strategies for coaches seeking to optimize training for the demands of competition.

Data from the present study support the use of position-specific training in the preparation of NCAA division I college football players for competitive games. Maximizing performance and limiting the effects of fatigue are critical challenges for performance coaches, and as such, accounting for the physical demands associated with weekly training and games is imperative. Modifying weekly training loads of individuals within position groups involved in greater high-speed running volumes and a higher number of acceleration and deceleration efforts may mitigate fatigue, accelerate recovery, and improve subsequent performance. The WR, DB, and LB position groups are exposed to greater running volumes, faster running velocities, and a higher number of acceleration and deceleration efforts in games compared to their offensive and defensive counterparts, and may benefit from carefully monitored and individualized training load prescriptions throughout the week. Additionally, while RB and TE groups do not accrue the total distance of the WR group during games, they are exposed to greater running volumes than the OL, which warrants individualized training load prescriptions based on the physical demands of competition. Clearly, performance coaches seeking to optimize physical performance characteristics associated with competition must differentiate training programs based upon position-specific movement demands.

Data obtained from the present study provide a better understanding of the demands of NCAA division I football and provide a foundation from which to implement a systematic approach to the development of individual and position-specific training programs. Future studies should examine how coaches seeking to enhance competitive performance, can manipulate individual and position-specific training programs to mitigate fatigue, enhance recovery, and optimize game-day performance.

# Chapter 4

## Quantification of Accelerometer Derived Impacts Associated With Competitive Games in NCAA Division I College Football Players

### 4.1 Introduction

American football is a field-based team-sport with competition characterised by repeated short-duration, high-intensity, intermittent movement patterns involving accelerations, decelerations, sprinting, and multi-directional running, followed by periods of low-intensity recovery and tactical strategizing between plays (111, 235). In addition to the running demands associated with American football, athletes are exposed to frequent collisions and blunt force trauma associated with repeated contact with opponents and the ground during tackling, blocking, and ball-carrying activities (216). Previous research (111, 194, 235) has provided some insight into positional movement profiles, including the quantification of high-intensity accelerations and decelerations and sprint distances, along with a rudimentary understanding of exercise to rest ratios performed during National Collegiate Athletic Association (NCAA) division I football games. However, there is currently limited quantitative information describing the number and intensity of impacts associated with competitive NCAA division I football games. Due to the intense physical demands associated with American football competition, a quantitative examination of position-specific impact profiles may provide an increased understanding of the competitive demands for individuals participating in NCAA division I football games, and novel insight for performance coaches seeking to develop position-specific training and recovery strategies.

Advances in game analysis technologies, such as global positioning system (GPS) and integrated accelerometry (IA), have provided a valid and reliable means of assessing activity profiles (45, 117, 118, 231) and an accurate measure of the impacts associated with collisions in contact team-sports (43, 50, 154, 158). The quantification of competitive movement demands associated with American football (235) and collisions in team-sport competition similar in nature to American football, including Rugby League (9, 74, 154, 155, 158, 160), Rugby Sevens (92), Australian rules football (148, 221, 240), and Rugby Union (50, 156) have been reported. Nevertheless, the unique characteristics of American football will dictate specific and distinct physical demands that require detailed examination.

The development of GPS technology with IA have allowed the physiological demands of practice and competition in contact team-sport to be quantified by the tracking of player movement demands (9, 74, 154, 158, 235, 242). Integrated triaxial accelerometers have proven to be a reliable means of measuring physical activity across multiple players in team-sport (24), and offer a valid tool for detecting the frequency and magnitude of impacts and collisions associated with practice and competition in contact team-sport (73). Impacts may differ in magnitude depending on the intensity of movement undertaken by an athlete and commonly occur in collision sport as a result of decelerations, high-intensity changes in direction, landing from jumps, falling to the ground, and collisions and tackles inherit to collision sport similar to American football (154). While the use of movement profiles collected from GPS and IA offers an assessment of athlete movement during sport-specific activity, the use of impact data collected by GPS and IA during competition and training may provide the most holistic assessment of volume and intensity of exercise in comparison to the traditionally used movement metrics. As such, the quantification of the impact profiles in NCAA division I college football may add novel insight to the physical loading demands placed upon athletes during competition.

Within American football, each position group has specific physiological and movement demands associated with unique technical and tactical requirements (141). The positional movement profile characteristics associated with NCAA division I football games have been reported (235) and significant ($p<0.05$) differences between positions groups on offense and defense for high-intensity movement demands have been established. Movement characteristics may provide a rudimentary understanding of the physical demands associated with competition, however, these measures fail to consider the physical demands associated with the contact nature of competitive football games. American football competition presents a unique model to study position-specific impact profiles that may be similar to other contact team-sports. The characteristics of repeated collisions and the associated blunt force trauma resulting from competition in Rugby League and Rugby Union players have been reported (43, 50, 154, 158), and significant ($p<0.05$) inter-positional differences in total impacts experienced have been demonstrated during competition (156, 220). However, uncertainty exists regarding the intensity and frequency of position-specific impact profiles of NCAA division I football players during competition. Despite the widespread inclusion of GPS and IA technology in collegiate American football programs, there remains a paucity of research regarding the characteristics of collisions experienced by players during competition. The accurate determination of impact forces experienced by players during games may provide sports performance specialists with novel insight into the position-specific demands of competition and highlight ways in which GPS and IA data may be used to optimize athlete performance programs.

The aims of the present study were to 1) examine the positional impact profiles of NCAA division I college football players associated with competitive game performance using IA technology, and 2) determine if positional differences in impact profiles exist within offensive and defensive teams. We hypothesized that significant positional differences will exist in the number and intensity of impacts associated with competitive performance in NCAA division I college football. Data obtained will provide information for performance coaches seeking to optimize position-specific training programs.

## 4.2 Methods

### 4.2.1 Experimental Approach to the Problem

To examine the positional impact characteristics during NCAA division I football games, portable accelerometer data were collected from players during 12 regular-season games. All games were 60 minutes in duration, comprised of four 15 minute quarters, each followed by a brief recovery period, and played outdoors between the hours of 12:00 and 21:00 over a period of thirteen weeks from September to November. All participants were required to participate in a minimum of 75% of the total offensive or defensive plays for the GPS and IA derived datasets to be included in the present study. Each individual GPS and IA dataset was characterized as constituting either offensive or defensive team performance, and subsequently divided into specific positional groups for the offense that included wide receivers (WR, 41 datasets), quarterbacks (QB, 12 datasets), running backs (RB, 41 datasets), tight ends (TE, 22 datasets), offensive linemen (OL, 37 datasets), and for the defense that included defensive backs (DB, 55 datasets), linebackers (LB, 36 datasets), defensive ends (DE, 33 datasets) and defensive tackles (DT, 17 datasets).

### 4.2.2 Subjects

Thirty-three National Collegiate Athletic Association (NCAA) Division I Football Bowl Subdivision (FBS) football players (age 20.7 ± 1.0 years; height 188.6 ± 7.2 cm; and mass 106.7 ± 19.6 kg) participated in the present study. Positional anthropometric data are presented in Table 7. All subjects were collegiate athletes whom had been selected to participate in the football program eight months prior to the commencement of the study. All participants in the present study completed the teams' off-season physical development training program that included a full-body strength and power training program and specific skills and conditioning sessions designed to simulate the demands of NCAA division I college football competition. The present study comprises statistical analysis of data collected as part of the day-to-day student athlete monitoring and testing procedures within the university's football program. Researchers were provided with de-identified GPS and IA datasets from twelve regular season games for analysis. De-identified data included participant playing position for the purposes of position-specific data analysis. Ethical approval was obtained from the university's human research ethics committee (RO-1929).

**Table 7.** Positional anthropometric data expressed as means ± standard deviation.

| Positional Anthropometric Data | | |
|---|---|---|
| **Position** | **Height (cm)** | **Mass (kg)** |
| **Defensive Tackle** (n=4) | 191.0 ± 0.4 | 135.2 ± 0.3 |
| **Defensive End** (n=4) | 193.4 ± 3.6 | 118.6 ± 5.8 |
| **Linebacker** (n=3) | 186.3 ± 3.4 | 105.5 ± 2.5 |
| **Defensive Back** (n=6) | 182.8 ± 5.2 | 86.4 ± 6.1 |
| **Offensive Line** (n=5) | 196.8 ± 3.9 | 136.8 ± 5.0 |
| **Tight End** (n=2) | 196.6 ± 1.1 | 115.0 ± 7.1 |
| **Running Back** (n=4) | 181.8 ± 2.0 | 97.8 ± 10.3 |
| **Quarterback** (n=1) | 192.4 ± 2.3 | 93.0 ± 1.6 |
| **Wide Receiver** (n=4) | 185.6 ± 10.5 | 91.3 ± 12.4 |

### 4.2.3 Procedures

### 4.2.4 Global Positioning System Units

The present study used commercially available GPS receivers (SPI HPU, GPSports, Canberra, Australia) which operated in a non-differential mode at a sampling frequency of 15 Hz. The GPS receivers also contain integrated triaxial accelerometers (IA), which operated at 100 Hz and assessed the frequency and magnitude of full-body acceleration ($m{\cdot}s^{-2}$) in three dimensions, namely, anterior-posterior, mediolateral, and vertical (143, 158). Impacts were derived from the vector of the X-Y-Z axes of the triaxial accelerometer and calculated as the square root of the sum of the squares of each axis, whereby 27.7 G was the maximum accelerometry output (91). Subjects had previously worn GPS and IA receivers in outdoor training sessions that included football-specific running and skill-related and game-simulated contact activities during a three-week pre-season training period. Prior to the commencement of each game, GPS receivers were placed outside for 15 minutes to acquire a satellite signal, after which, receivers were placed in a custom designed pocket attached to the shoulder pads of the subjects. Shoulder pads were custom-fit for each individual, thereby minimizing movement of the pads during games. The GPS and IA receivers used in the present study (66 g; 74 mm x 42 mm x 16 mm) were positioned in the center of the upper back, slightly superior to the scapulae. Subjects were outfitted with the same GPS receiver for each of the twelve games. Following the completion of games, GPS receivers were removed from the shoulder pads, and subsequently downloaded to a computer for analysis utilizing commercially available software (Team AMS, GPSports, Canberra, Australia). The GPS and IA receivers used in the present study have demonstrated both inter- and intra-accelerometer reliability (CV = 1.87 – 2.21%) (132), while similar integrated accelerometers have been validated for quantifying the number and intensity of collisions in Rugby League (73) and measuring peak impacts in team-sport (CV = 4.8%, filtered at cut-off frequency of 12Hz) (241).

Data provided from IA were assessed as impact profile variables including very light, light to moderate, moderate to heavy, heavy, very heavy, and severe impacts. Classifications of parameters of impact profile variables are described below and presented in Table 8. Each of the GPS and IA derived variables measured in the present study were calculated using commercially available software (Team AMS, GPSports, Canberra, Australia). The impact classification system utilized in the present study was based on methods previously described in Rugby League (154, 158), Rugby Union (43, 50, 156) and manufacturer recommendations (GPSports, Canberra, Australia). GPSports reports peak accelerations, irrespective of the nature of the peaks, from which impact forces can be calculated, given the fact that acceleration is proportional to force if mass is constant (242).

### 4.2.5 Impact Classification System

Player exposure to impact was determined via accelerometer data provided in 'G' force. A classification system within Team AMS (GPSports, Canberra, Australia) software allows for six zones of impact to be preset and used for subsequent analysis. Zone one is indicative of the lowest intensity of impact, with each zone progressively categorizing impact intensity to zone six, reflecting the highest impact and intensity of movement. Each impact classification was coded as one of six intensities of impact (Table 8). Very light impacts such as accelerations, decelerations, and changes of direction were considered to be 5.0 - 6.0 G. Light to moderate impacts, such as minor collisions with other players and contact with the ground, were considered to be 6.1 – 6.5 G. Moderate to heavy impacts resulting from physical contact with the opposition at moderate velocities were considered 6.6 – 7.0 G. Heavy impacts from high-intensity collisions were classified as 7.1 – 8.0 G, while very heavy impacts resulting from high-intensity collisions and high velocities were classified as 8.1 – 10.0 G, and severe impacts resulting from high-intensity collisions between players traveling at high velocities, were classified as those exceeding 10 G.

**Table 8**. Impact Classification System

| **Impact Zones** | **Gravitational Force** (G Force) | **Impact Classification** |
|---|---|---|
| Zone 1 | 5.0 – 6.0 | Very Light |
| Zone 2 | 6.1 – 6.5 | Light to Moderate Impact |
| Zone 3 | 6.6 – 7.0 | Moderate to Heavy Impact |
| Zone 4 | 7.1 – 8.0 | Heavy Impact |
| Zone 5 | 8.1 – 10.0 | Very Heavy Impact |
| Zone 6 | > 10 | Severe Impact |

### 4.2.6 Statistical Analyses

All movement variables from the present study were presented as descriptive statistics, mean ± standard deviation (SD). Hypothesis testing was conducted to determine any main effects for impact profile data between position groups on the offensive and defensive teams. A one-way ANOVA was used to determine positional group main effects. In the event homogeneity of variance assumption was violated, a Welch Robust Test of Equality was used to determine main effects between position groups. For all main effects detected by a one-way ANOVA, post-hoc Bonferroni tests were utilized. Alpha intervals for all hypothesis testing were set at $p<0.05$. To determine the magnitude of main effects and interactions, partial eta-square ($n^2$) effect size statistics were adopted, which indicate the percentage of variance accounted for by the effect, with values of 0.01 – 0.06, 0.06 – 0.15, and > 0.15 considered small, moderate, and large, respectively. All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS for Windows, version 14.0; SPSS, Inc., Chicago, IL. USA).

## 4.3 Results

### 4.3.1 Offense

Significant ($p<0.001$) main effects from ANOVA testing were reported for all impact profile variables measured in the present study for the offensive position groups (Table 9). Post-hoc analysis of impact profile variables, revealed significant ($p<0.05$) inter-position differences across all impact zones, with the exception of zone 5. The WR position group sustained significantly ($p<0.001$) more very light (zone 1) impacts than all other offensive position groups, while the OL position group underwent significantly ($p<0.01$) more very light impacts than RB and QB position groups. Analysis of light to moderate impacts (zone 2) demonstrated a significantly ($p<0.001$) greater number of impacts for WR than all other offensive position groups. Similarly, both TE and OL position groups underwent significantly ($p<0.01$) more light to moderate impacts than RB and QB position groups. The number of moderate to heavy (zone 3) impacts sustained during games were similar among WR, TE, and OL position groups, and significantly ($p<0.001$) greater than both QB and RB position groups. The WR and OL position groups experienced significantly ($p<0.001$) more heavy (zone 4) impacts than both the RB and QB position groups. Analysis of very heavy (zone 5) impacts revealed no significant ($p<0.05$) inter-position differences, while the number of severe (zone 6) impacts was significantly ($p<0.05$) greater for the RB position group than the WR, TE, and OL position groups. Finally, the QB position group sustained significantly more severe (zone 6) impacts than the TE position groups.

**Table 9.** Offensive positional impacts profiles. Data are means ± standard deviations. $^{W}$ $^{W}$Significantly different ($p < 0.05$) for WR. $^{R}$ Significantly different ($p < 0.05$) for RB. $^{Q}$ Significantly different ($p < 0.05$) for QB. $^{T}$ Significantly different ($p < 0.05$) for TE

| **Impact Zones** (Count of events) | **Wide Receiver (WR)** | **Running Back (RB)** | **Quarterback (QB)** | **Tight End (TE)** | **Offensive Linemen (OL)** | **ANOVA Main Effects** (F, p-value, $n^2$) |
|---|---|---|---|---|---|---|
| **Zone 1** Very Light | 4093 ± 791.6 | 1929.9 ± 469.2$^{WT}$ | 2060.7 ± 241.8$^{W}$ | 2615.3 ± 725.7$^{WR}$ | 2732.8 ± 415.4$^{WRQ}$ | F (4,59) = 66.84, p < 0.001, $n^2$ = 0.674 |
| **Zone 2** Light to Moderate | 1155.9 ± 401.7 | 582.7 ± 184.8$^{WT}$ | 333.3 ± 109.9$^{WT}$ | 869.5 ± 255.6$^{WRQ}$ | 851.6 ± 222.9$^{WRQ}$ | F (4,59) = 52.25, p < 0.001, $n^2$ = 0.470 |
| **Zone 3** Moderate to Heavy | 172.7 ± 56.7 | 78.4 ± 31.4$^{W}$ | 44.3 ± 11.3$^{W}$ | 175.2 ± 58.4$^{QR}$ | 162.1 ± 103.9$^{QR}$ | F (4,66) = 72.63, p < 0.001, $n^2$ = 0.358 |
| **Zone 4** Heavy | 38.4 ± 14.7 | 21.4 ± 10.4$^{W}$ | 15.5 ± 5.3$^{W}$ | 31.6 ± 14.5$^{Q}$ | 35.9 ± 18.7$^{QR}$ | F (4,61) = 22.76, p < 0.001, $n^2$ = 0.245 |
| **Zone 5** Very Heavy | 11.1 ± 5.5 | 9.5 ± 4.9 | 9.3 ± 5.7 | 9.1 ± 4.4 | 12.9 ± 6.8 | F (4,148) = 2.66, p < 0.05, $n^2$ = 0.067 |
| **Zone 6** Severe | 12.3 ± 5.0 | 16.6 ± 7.9$^{W}$ | 13.6 ± 5.9 | 5.9 ± 2.3$^{WRQ}$ | 11.5 ± 5.9$^{RT}$ | F (4,53) = 25.54, p < 0.001, $n^2$ = 0.243 |

### 4.3.2 Defense

Significant ($p<0.001$) main effects from ANOVA testing were reported for all impact profile zones measured in the present study for the defensive position groups, with the exception of zone 2 impacts (Table 10). Post-hoc analysis of impact profile variables, revealed significant ($p<0.05$) inter-position differences across all impact zones, with the exception of zone 2 and zone 6. The DB position group sustained significantly ($p<0.001$) more very light (zone 1) impacts than the DT and DE position groups, while the LB group was involved in significantly (p<0.001) more very light impacts than the DT position group. The DT position group was involved in significantly (p<0.001) more moderate to heavy (zone 3), heavy (zone 4), and very heavy (zone 5) impacts than all other defensive position groups, while the DE position group sustained significantly more (p<0.01) heavy and very heavy impacts than the DB position group. The DT position group was involved in more light to moderate (zone 2) impacts than all other defensive position groups, while the DE position group engaged in more severe (zone 6) impacts than any other defensive group, however none of the inter-position differences within either of these impact zones reached a level of significance (p<0.05).

**Table 10.** Defensive positional impacts profiles. Data are means ± standard deviations. $^{B}$Significantly different (p < 0.05) for DB. $^{T}$ Significantly different (p < 0.05) for DT.

| **Impact Zones** (Count of Events) | **Defensive Backs (DB)** | **Defensive Tackles (DT)** | **Defensive Ends (DE)** | **Linebackers (LB)** | **ANOVA Main Effects** (F, p-value, $n^2$) |
|---|---|---|---|---|---|
| **Zone 1** Very Light | 2938.9 ± 569.1 | 1847.4 ± 431.1 $^{B}$ | 2319.1 ± 682.5 $^{BT}$ | 2638.9 ± 566.4 $^{T}$ | 18.2, p < 0.001, 0.285 |
| **Zone 2** Light to Moderate | 581.5 ± 186.6 | 699.2 ± 215.6 | 532.9 ± 202.2 | 545.8 ± 287.3 | 2.3, p = .074, 0.049 |
| **Zone 3** Moderate to Heavy | 100.9 ± 42.5 | 198.4 ± 102.4 $^{B}$ | 105.9 ± 50.4 $^{T}$ | 100.1 ± 47.5 $^{T}$ | 14.9, p < 0.001, 0.247 |
| **Zone 4** Heavy | 19.3 ± 9.5 | 49.6 ± 20.9 $^{B}$ | 31.4 ± 17.2 $^{BT}$ | 23.6 ± 13.3 $^{T}$ | 21.5, p < 0.001, 0.321 |
| **Zone 5** Very Heavy | 7.4 ± 4.1 | 18.0 ± 10.2 $^{B}$ | 11.7 ± 5.8 $^{BT}$ | 9.3 ± 6.0 $^{T}$ | 14.6, p < 0.001, 0.243 |
| **Zone 6** Severe | 9.6 ± 4.9 | 10.6 ± 4.6 | 13.2 ± 6.9 | 12.7 ± 7.4 | 3.1, p < 0.001, 0.640 |

### 4.4 Discussion

The present study examined the impact profiles associated with competitive games in NCAA division I college football players using portable IA technology, and assessed differences in positional groups within offensive and defensive teams. The results of the present study provide novel insight into the competitive demands experienced by NCAA division I college football players, and may provide scope for the design of position-specific and game-specific physical preparation strategies for coaches seeking to optimize training for the demands of competition. Results from the present study confirm our hypothesis that significant ($p<0.05$) differences in the number and intensity of impacts associated with competition exist between playing positions in NCAA division I college football players. The most notable findings for competitive game impact profile characteristics of offensive position groups were the WR position group undergoing more zone 1 and 2 (very light and light to moderate) impacts than all other offensive position groups, while the WR and OL group participated in more zone 3 and 4 (moderate to heavy and heavy) impacts than the RB group. The RB position group recorded the greatest number of severe impacts throughout the course of competition, which may reflect the characteristic high-velocity collisions with defenders associated with the positional demands of being the primary offensive ball carrier. Defensively, the DB and LB position groups were involved in more zone 1 impacts than all other position groups. The DT group participated in more zone 3, 4, and 5 (moderate to heavy, heavy, and very heavy) impacts than all other defensive position groups, which may be attributed to the physical demands of the DT position, often involving physical contact with numerous offensive players on each play throughout the course of competition.

Comparing the findings of the present study with the existing knowledge of positional game demands is problematic due to the lack of research on impact profiles in American football players. Positional analysis in contact team-sport similar to American football, including Rugby League (154, 158) and Rugby Union (43, 50, 156, 220), have demonstrated interpositional differences in the quantity and intensity of impacts associated with competition, supporting the findings of the present study. Although the influence of the number and intensity of impacts sustained during competition on the duration of post-game recovery in Rugby League players has been investigated (154, 158), and the biochemical and endocrine responses to competitive games in American football and Rugby league players have been reported (142, 159), there is a lack of research quantifying the relationship between the physical demands of competition and the time-course of recovery associated with college football games. Accordingly, there is a need to establish the relationship between the physical demands of games, including movement and impact profiles, and the subsequent duration of recovery in NCAA division I football players, to provide insight into the effects of competition on athlete recovery.

The present study found significant ($p<0.05$) inter-position differences in the number of impacts encountered during competitive NCAA division I football games. The WR position group was involved in significantly ($p<0.001$) more zone 1 impacts than all other offensive position groups. Similarly, on defense, the DB position group recorded significantly ($p<0.001$) more zone 1 impacts than both the DT and DE position groups, while the LB group recorded significantly ($p<0.001$) more than the DT position group. The manufacturer (GPSports, Canberra, Australia) of the GPS and IA receivers used in the present study have indicated that low-intensity impacts (2.0-6.0G) are commonly attributed to walking and running, and thus a large amount of very light impacts may be a reflection of running volume throughout the course of competition (91). Additionally, high-intensity changes of direction, falling to the ground, landing from jumps, blocking, collisions, and tackles are all capable of eliciting high-intensity impacts (91). Significant ($p<0.05$) inter-position differences in running volumes in NCAA division I players participating in competitive games have been demonstrated (235). Wellman et. al. (235) examined movement profiles associated with competitive games in NCAA division I football players and reported the WR group covered significantly ($p<0.05$) more total distance than all other offensive position groups, while the DB and LB position groups covered significantly ($p<0.05$) more total distance than both DT and DE position groups. The results of Wellman et. al. (235) support the findings of the present study, indicating the increased number of very light impacts detected in the WR and DB position groups may be attributed to the increased running volumes experienced as a result of the unique position-specific demands of these groups. Positional alignment at the commencement of each play that provides greater distance from the placement of the football gives these athletes a larger area for movement, providing increased movement requirements during plays. Additionally, the WR and DB cover more distance between plays as they are required to jog back to the line of scrimmage at the conclusion of plays, which may be a distance of 20-30 m to either huddle or re-assume their alignment for subsequent play, while other positions characteristically walk short distances during recovery between plays (194).

Offensively, the WR and OL position groups sustained significantly ($p<0.05$) more zone 2, 3, and 4 impacts than the RB and QB groups. While no significant inter-position differences were demonstrated with respect to very heavy impacts, the RB position group was involved in significantly ($p<0.05$) more zone 6 (severe) impacts than all offensive position groups, with the exception of the QB position group. These findings are substantiated by previous descriptions of the nature of severe impacts in contact team-sport (158). McLellan et. al. (158) described severe impacts as being indicative of high-intensity collisions with the opponent, making a direct front-on tackle on an opponent traveling at a high velocity, or being tackled by multiple opponents while running at maximal velocity. The RB position is primarily responsible for carrying the football on running plays and catching the ball on short passing plays, in addition to blocking DT, DE, and LB on passing plays, which require protection of the QB. The responsibility of running with the football at high velocities lends itself to direct blunt force trauma, often from multiple opponents, and supports the findings of the present study, which indicated an increased number of severe impacts when compared to other offensive positions. Defensively, there were no significant differences between position groups with respect to light to moderate impacts, however the DT group registered significantly ($p<0.05$) more zone 3, 4, and 5 impacts than all other defensive position groups. Additionally, the DE position group was involved in significantly ($p<0.05$) more zone 4 and 5 impacts than the DB group. The greater number of zone 4 and 5 impacts demonstrated within the DT and DE position groups may result from the position-specific demands of these position groups, including rapid accelerations at the commencement of each play, followed by contact with the opposing offensive player, and the subsequent pursuit and tackling of the ball carrier.

Inter-positional differences in impact profiles resulting from Rugby Union competition revealed significant ($p<0.05$) differences between forwards and backs which is consistent with the findings of the present study for offensive and defensive positions (156, 220). The significant differences in zone 1-4 impact counts between the WR and OL group when compared to the RB and QB group highlight distinct physiological impact characteristics associated with competition, which may require different training and recovery protocols to achieve optimal performance. The positional differences in the present study may be explained by the position-specific requirements of these individuals. Additionally, the tactics of the offensive team employed during games, namely the number of running and passing plays undertaken, may affect the positional impact distribution. During NCAA division I football games, the WR group is involved in significantly ($p<0.05$) more maximal acceleration and deceleration efforts than all other offensive position groups (235), likely resulting from the frequent changes of direction due to repeated route running. Additionally, the WR group is responsible for blocking the opposition on running plays and is involved in impacts resulting from physical collisions associated with carrying the ball following a reception on passing plays. The OL position group engages in physical contact with the opposition on nearly every play, with the intensity and quantity of impacts presumably dictated largely by offensive strategy. Running plays typically require the OL group to quickly accelerate forward or laterally from a stationary position, initiate contact with the opposition, and move the defender thereby creating a running lane for the ball carrier. Passing plays involve the OL group moving backward or laterally in attempt to protect the QB, while waiting for the opposition to initiate contact. The RB group was involved in significantly ($p<0.05$) more severe impacts than all other offensive position groups with the exception of the QB group. These findings are likely the result of impacts with opponents, and subsequent impact with the ground, resulting from carrying the ball during running plays. The lack of a significant difference in the number of severe impacts between the RB and QB position groups may be due to offensive strategy. On plays involving the QB as the ball carrier, increased opportunity exists for multiple impacts with the opposition, and similarly, as the number of passing attempts increases, there is greater possibility of the QB being sacked or knocked down.

Defensively, while no significant inter-positional differences were observed for light to moderate impacts, significant ($p<0.05$) differences were demonstrated in the number of zone 3, 4, and 5 impacts between the DT group and all other defensive position groups. Characteristically, players in the DT position group accelerate short distances and perform rapid change of direction movements before engaging individual or multiple OL, followed by accelerating to pursue and tackle the ball carrier. The DB group initiates play further from the line of scrimmage, is primarily responsible for defending the WR on passing plays, and provides secondary support on running plays, thereby limiting the amount of physical contact with the opposition. The LB group characteristically commences play 4-5 m from the line of scrimmage and is generally responsible for providing support on running plays, in addition to defending TE and RB on passing plays. Due to the increased responsibilities in defending running plays within the position-specific responsibilities of the LB group compared to the DB group, and a closer alignment to the line of scrimmage at the initiation of play, the opportunity for physical contact with offensive players is increased. The present study indicated a larger number of zone 4 and 5 impacts for the LB group when compared to the DB group, although these results did not reach significance. Aligning directly on the line of scrimmage prior to the commencement of each play, provides opportunity for the DT position group to be involved in physical contact from multiple players on every play, which is indicated in the present study with significantly ($p<0.05$) more zone 3, 4, and 5 impacts recorded for the DT group than all other defensive positions. In similar contact team-sport, significant ($p<0.05$) correlations have been demonstrated between the number of high-intensity (>7G) impacts sustained and post-match neuromuscular performance decrements and markers of skeletal muscle damage (154, 158). As such, the accurate monitoring and prudent modification of practice impact loads of position groups involved in significantly more zone 4-6 impacts during competition may enhance recovery and improve subsequent competitive performance.

Significant inter-position differences in the intensity and distribution of impacts associated with NCAA division I college football competition exist. The greater number of zone 1 and 2 impacts for the WR, DB, and LB groups may be attributed to the significant differences in competitive game running volumes, including accelerations and decelerations, between position groups previously demonstrated (235). The position-specific physicality required of the OL group presumably resulted in more zone 3 and 4 impacts, while the significant differences in severe impacts of the RB position group, compared to other offensive groups, may result from high-intensity collisions from direct tackles at high-velocities, or being tackled by multiple opposing players, as described in investigations of impacts associated with Rugby

League competition (154, 158). The starting position of the DT group upon commencement of each play, along with rapid changes of direction and physical contact with multiple opponents which generally characterizes DT positional demands, resulted in more zone 3, 4, and 5 impacts than all other defensive position groups. Collectively, the results of the present study highlight distinct impact profiles for offensive and defensive teams, which may require the development of position-specific training and recovery protocols.

The results of the present study provide novel insight into the impact profiles of NCAA division I college football games and provide physical performance staff with quantified information. The present study demonstrated substantial differences in positional impact profiles associated with NCAA division I football games, emphasizing the importance of position-specific training to appropriately prepare players for the rigors of competition.

### 4.5 Practical Applications

The present study provided a novel analysis of the number and intensity of impacts associated with NCAA division I college football games. The findings of this study suggest that repeated high-intensity impacts during NCAA division I football games are position specific in nature and support the use of position-specific training in the preparation of NCAA division I college football players for competitive games. Data from the present study augment our understanding of the competitive demands experienced by NCAA division I college football players, and provide scope for position-specific training strategies for performance coaches seeking to optimize competitive performance.

Maximizing performance and mitigating the effects of fatigue present unique challenges to performance coaches, and consequently, quantifying the physical demands associated with weekly practice and competition is critical. In contact team-sport similar to American football, the number of impacts exceeding 7 G has been significantly correlated with decreases in neuromuscular performance following competition (154). During the in-season period judicious monitoring, and the subsequent alterations of weekly practice and conditioning loads of individuals within position groups involved in large numbers of impacts, particularly those registering as heavy, very heavy, and severe, may reduce fatigue, expedite recovery, and improve competitive performance. As such, the DT, OL, and WR position groups may benefit from position-specific, and perhaps, individually prescribed practice loads. Because the OL and DT position groups often compete against one another in practice, limiting the number of live contact drills and scrimmage situations may result in a reduction of intense impacts sustained during the course of a practice week, possibly enhancing recovery and improving subsequent performance. Limiting the amount of contact the WR position sustains in practice sessions is common in American football, and this rationale is substantiated by the present study. Given the significant quantity of severe impacts sustained by the RB position, performance coaches should monitor, and in some cases, reduce the impact load of individual practice sessions by limiting the number of scrimmage situations in which the RB group is involved. Data obtained from the study contribute new insight into the competitive demands of NCAA division I college football and provide a foundation from which to implement a systematic approach to the development of individual and position-specific training prescriptions. During the pre-season practice period, monitoring and periodizing training loads based upon position-specific impact profiles may allow performance specialists to scale the intensity of practices to better prepare athletes for forces encountered during competition.

# Chapter 5

## Movement Demands and Perceived Wellness Associated With Pre-Season Training Camp in NCAA Division I College Football Players

### 5.1 Introduction

American college football is a physically demanding, full-contact team sport in which players are required to participate in competition necessitating high levels of muscular strength, power, speed and agility, and repeated high-intensity movements (196). In addition to the intense movement demands associated with American football, athletes are exposed to frequent collisions and blunt force trauma associated with repeated contact with opponents and the ground during tackling, blocking, and ball-carrying activities (216). Previous investigations (111, 194, 235) have added to our knowledge of player movement characteristics during National Collegiate Athletic Association (NCAA) division I football competition providing an increased understanding of the positional movement profiles, including the quantification of sprint distances and high-intensity accelerations and decelerations, in addition to a basic understanding of exercise to rest ratios. An additional investigation (236) of NCAA division I college football has revealed the frequency and intensity of impacts and rapid changes of direction, and provided a quantification of the position-specific number and intensity of impacts per game. The movement patterns of NCAA division I football players during competition using global positioning systems (GPS) technology have been reported (235), however limited data (56) exist describing the movement profiles experienced by players during pre-season training camp that are synonymous with college football competition.

The development of GPS technology with integrated triaxial accelerometers (IA) have provided a means of quantifying the physical demands of training and competition in contact team sports (9, 74, 160, 235). Improvements in GPS technology have resulted in improved accuracy (115), and have provided a valid and reliable means of assessing activity profiles in team sports (45, 117, 118, 231). Additionally, IA have demonstrated reliability (24) as a means of measuring physical activity across multiple players in team sports, and strong inter-unit relationships (r=0.996-0.999) have been demonstrated during high-intensity contact team sport activity.

College football teams that are similar to other collision-based team sports (44, 135), participate in an intensified pre-season training camp that typically commences 4-5 weeks prior to the first competition and is associated with a maximum of 29 practice sessions (176). National Collegiate Athletic Association rules govern practice guidelines, permitting teams to designate up to four days for multiple practices, provided the practices do not exceed five total hours combined, and they do not occur on consecutive days (176). Programming training loads during the pre-season practice period, which maximize positive physiological adaptations, and minimize excessive fatigue that may be associated with maladaptation, can be challenging for coaches and performance staff. While the programming of individual training load prescriptions presents a difficulty in team sports, the prudent monitoring of the individual response to these loads is fundamental for maximizing positive training adaptations (20).

Monitoring training load involves not only objectively quantifying the volume, intensity, and duration of physical activity completed, commonly referred to as external load, but also the internal load, or the relative physiological and psychological stress imposed as a result of training (97). Previous research in contact team sport, with competitive demands indicative of NCAA division I football, has examined potential measures of an athlete's internal response, including perceived wellness, and the biochemical, and neuromuscular response to training and competition (153, 230), however ambiguity exists as to the methods that may be most pertinent to quantify this response (97).

Subjective measures of mood state and well-being are efficient, inexpensive, and non-invasive (150), have demonstrated sensitivity to training stress, exhibiting a dose-response relationship with training load (190) (209), and have been established to be as effective as objective measures in identifying training stress (129). In elite contact team sport, significant correlations have been reported between fluctuations in daily training load and changes in subjective ratings of wellness (27). During intensified periods of competition in sports characteristic of American football, significant changes in perceived well-being accompany performance decrements, decreases in neuromuscular power, and increases in biochemical markers of muscle damage (116).

There exist a small number of subjective questionnaires that have demonstrated accuracy in assessing athletes' response to training and competition loads including the Recovery-Stress Questionnaire for Athletes (RESTQ-Sport) (128), Athlete Burnout Questionnaire (ABQ) (189), and Daily Analysis of Life Demands for Athletes (DALDA) (204) among others. Due to the comprehensive and time-consuming nature of the subjective questionnaires commonly used to monitor athletes' internal training response, the practicality of their implementation presents considerable logistical challenges in a high-performance applied setting (228). A survey of the current trends in fatigue monitoring among Australian and New Zealand high-performance sport revealed that 84% of respondents used self-report questionnaires, 80% of which were custom designed forms consisting of 4-12 items (225). Consequently, it has been recommended that coaches and performance staff utilize brief, customized questionnaires, similar to the one employed by McLean et. al (153) within an athlete monitoring system (106).

Despite recent advances in our understanding of movement characteristics associated with competition, GPS-derived movement characteristics of multiple position groups resulting from pre-season training camp practices in NCAA division I football players remain unknown. Additionally, the effects of pre-season training camp practice loads that are commonly undertaken in division I college football on the subjective perceptions of wellness are unclear. A more comprehensive understanding of the physiological demands and the resulting subjective psychological response associated with pre-season training camp practice will augment our understanding of the demands of NCAA football players, providing performance coaches a platform to develop training programs that replicate the physical demands of training camp, and allow for the individualization of practice training loads and recovery strategies to enhance performance throughout the pre-season period. The aim of the present study was (a) to examine the positional movement demands associated with pre-season training camp practices in NCAA division I college football players using portable GPS and IA technology and (b) to assess daily perceived wellness associated with pre-season training camp utilizing a modified questionnaire to determine if GPS-derived measures from the preceding day influence perceived ratings of wellness on the following day. We hypothesized that there will be substantial positional differences in the movement demands of NCAA division I football players during pre-season training camp practice, in addition to substantial differences in perceived wellness scores based on the movement demands resulting from practice on the previous day.

## 5.2 Methods

### 5.2.1 Experimental Approach to the Problem

To examine the positional movement characteristics during NCAA division I football pre-season training camp, portable GPS and IA data were collected from players during 20 pre-season practices completed over the course of 20 days. Each individual GPS and IA dataset was divided into specific positional groups for the offense that included wide receivers (WR, 91 observations), quarterbacks (QB, 19 observations), running backs (RB, 40 observations), tight ends (TE, 53 observations), offensive linemen (OL, 80 observations), and for the defense that included defensive backs (DB, 100 observations), linebackers (LB, 80 observations), defensive ends (DE, 40 observations) and defensive tackles (DT, 47 observations). To determine positional movement profiles, each practice completed was assessed as a single observation.

To assess perceived wellness associated with pre-season training camp practices, a custom designed form (153) was completed by participants every morning prior to any physical activity. A total of 469 observations were included in present examination which included 78 WR observations, 16 QB observations, 34 RB observations, 46 TE observations, 68 OL observations, 85 DB observations, 68 LB observations, 34 DE observations, and 40 DT observations. For the purposes of examining perceived wellness associated with pre-season camp, only practice data where a survey was completed on the following day were included in the analysis. For days where two practices occurred, and a survey was taken the following day, both practices were aggregated. Two practices occurred on three separate days, namely days 6, 8, and 13 of pre-season training camp. The first two practices of pre-season training camp were completed in helmets only, and therefore were omitted from the analysis

### 5.2.2 Subjects

Twenty-nine NCAA division I Football Bowl Subdivision (FBS) football players (age 20.6 ± 1.1 years; age range 18.3 – 22.8; height 187.9 ± 6.5 cm; and mass 108.9 ± 19.8 kg) participated in the present study. Positional anthropometric data are presented in Table 11. All subjects were collegiate athletes whom had been selected to participate in the football program prior to the commencement of the study. All participants in the present study completed the teams' summer off-season physical development training program that included a full-body strength and power training program and specific skills and conditioning sessions designed to simulate the demands of NCAA division I college football practice. The present study comprises the statistical analysis of data collected as part of the day-to-day student athlete monitoring and testing procedures within the university's football program. Ethical approval was obtained from the university's Institutional Review Board and all subjects signed an institutionally approved informed consent document prior to participating in the study.

**Table 11.** Position group heights and mass expressed as means ± standard deviation.

| Position Group Height and Mass | | |
|---|---|---|
| **Position** | **Height (cm)** | **Mass (kg)** |
| **Defensive Tackle** | 192.2 ± 4.5 | 133.3 ± 6.6 |
| **Defensive End** | 192.4 ± 0.9 | 118.9 ± 0.9 |
| **Linebacker** | 185.0 ± 0.7 | 105.5 ± 2.73 |
| **Defensive Back** | 182.6 ± 2.3 | 90.6 ± 5.7 |
| **Offensive Line** | 197.2 ± 3.3 | 142.2 ± 5.3 |
| **Tight End** | 192.2 ± 2.6 | 111.8 ± 3.7 |
| **Running Back** | 180.3 ± 3.8 | 96.1 ± 6.3 |
| **Quarterback (n=1)** | 182.9 | 100.5 |
| **Wide Receiver** | 185.4 ± 6.9 | 87.4 ± 5.8 |

### 5.2.3 Procedures

### 5.2.4 Global Positioning System Units

Positional movement data were collected in 20 practice sessions using a commercially available GPS unit, which sampled at 10 Hz (OptimEye S5; Catapult Innovations, Melbourne, Australia). The unit included a triaxial accelerometer (IA) which operated at 100 Hz and assessed the frequency and magnitude of full-body acceleration ($m \cdot s^{-2}$) in three dimensions, namely, anterior-posterior, mediolateral, and vertical (143, 158). Prior to the commencement of each practice, GPS receivers were placed outside for 15 minutes to acquire a satellite signal, after which, receivers were placed in a custom designed pocket attached to the shoulder pads of the subjects. Shoulder pads were custom-fit for each individual, thereby minimizing movement of the pads during practices. The GPS and IA receivers used in the present study were positioned in the center of the upper back, slightly superior to the scapulae. Subjects were outfitted with the same GPS receiver for each of the 20 practices. Following the completion of practices, GPS receivers were removed from the shoulder pads, and subsequently downloaded to a computer for analysis utilizing commercially available software (Catapult Sprint 5.1, Catapult Innovations, Melbourne, Australia). Combined tri-axial accelerometer data were presented as PlayerLoad$^{TM}$ (PL), which is a modified vector magnitude expressed as the square root of the sum of the squared instantaneous rates of change in acceleration in each of the three planes and divided by 100 (24). Boyd and colleagues (24) have demonstrated the intra-unit (0.91-1.05 % coefficient of variation [CV]) and inter-unit (1.02-1.10 % CV) reliability of PL and determined its inter-unit reliability in Australian rules football matches (1.90% CV). Data provided from GPS receivers were assessed as movement profiles variables including total, low-intensity, medium-intensity, high-intensity, and sprint running distances (m), acceleration and deceleration distances (m), and PL (arbitrary units). Classifications of parameters of movement profile variables are described below and presented in Table 12. Each of the GPS and IA variables measured in the present study was calculated using commercially available software (Catapult Sprint 5.1, Catapult Innovations, Melbourne, Australia).

### 5.2.5 Movement Classification System

Movement profile classifications have been described for game analysis in American football (235) and similar contact team sports (155, 160). The classification profile utilized in the present study was selected by the researchers to more accurately reflect the demands of American football (235). Each movement classification was coded as one of four speeds of locomotion (Table 12). Low-intensity movements, such as standing, walking and jogging, were considered to be 0 – 12.9 $km \cdot h^{-1}$, medium-intensity movements, such as striding and running, were considered to be 13.0 – 19.3 $km \cdot h^{-1}$, high-intensity movements, such as fast running for some positional groups, and sprinting for others, were classified as 19.4 – 25.8 $km \cdot h^{-1}$, and sprinting movements were classified as exceeding 25.8 $km \cdot h^{-1}$. Short duration high-intensity movements, or measures of acceleration and deceleration, were classified as four groups, specifically low-intensity (0 – 1.0 $m \cdot s^{-2}$), medium-intensity (1.1 – 2.0 $m \cdot s^{-2}$), high-intensity (2.1 – 3.0 $m \cdot s^{-2}$), and maximal-intensity (> 3.0 $m \cdot s^{-2}$).

**Table 12.** Movement Classification System

| Speed of Locomotion | |
|---|---|
| **km·h$^{-1}$** | **Movement Classification** |
| 0 – 12.9 km·h$^{-1}$ | Low-Intensity |
| 13.0 – 19.3 km·h$^{-1}$ | Medium-Intensity |
| 19.4 – 25.8 km·h$^{-1}$ | High-Intensity |
| ≥ 25.9 km·h$^{-1}$ | Sprinting |
| **Acceleration and Deceleration** | |
| **m·s$^{-2}$** | **Movement Classification** |
| 0 – 1.0 m·s$^{-2}$ | Low-Intensity |
| 1.1 – 2.0 m·s$^{-2}$ | Medium-Intensity |
| 2.1 - 3.0 m·s$^{-2}$ | High-Intensity |
| > 3.0 m·s$^{-2}$ | Maximal-Intensity |

### 5.2.6 Wellness Questionnaire

During pre-season training camp, athletes completed a daily wellness questionnaire based on prior recommendations by Hooper and Mackinnon (106) and previous research in Rugby League, both during intensified periods of training and following competition (116, 153, 230). This approach to athlete monitoring is consistent with survey data outlining the fatigue-monitoring practices utilized within high-performance sport in Australia and New Zealand (225). The questionnaire utilized in the present study assessed six factors of perceived wellness including fatigue, soreness, sleep quality, sleep quantity, stress, and mood on a 1-5 Likert scale in one-point increments, with higher scores representing more favorable responses (Figure 1). Although this modified questionnaire, similar to that utilized by McLean et. al. (153), has not been validated, traditional questionnaires with evidence of validity including RESTQ-Sport (128), ABQ (189), and DALDA (204) are often viewed as too lengthy and lacking in sport-specific focus to be utilized in applied settings. Simple composite measures have demonstrated sensitivity to changes in training load and recovery states of team sport athletes, and provide reliable and actionable data to coaches and performance staff (27, 86, 153). The questionnaire was completed via pen and paper every day before breakfast between 7:00 am and 9:00 am, prior to any physical activity, and subsequently downloaded to a laptop for analysis. Similar scales have been shown to have good reliability and validity (53).

**Figure 1. Wellness Questionnaire**

| Category | 5 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|
| **Fatigue** | Very Fresh | Fresh | Normal | More Tired Than Normal | Always Tired |
| **Sleep Quality** | Very Restful | Good | Difficulty Falling Asleep | Restless Sleep | Cannot Sleep |
| **General Soreness** | Feeling Great | Feeling Good | Normal | Increase in Soreness / Tightness | Very Sore |
| **Stress Levels** | Very Relaxed | Relaxed | Normal | Feeling Stressed | Very Stressed |
| **Mood** | Very Positive Mood | Generally Good Mood | Less Interested in Others / Activities than Normal | Aggravated / Short Tempered | Very Annoyed / Irritable |
| **How Many Hours Did You Sleep?** (Sleep Quantity) | More Than 10 Hrs. | 8-10 Hrs. | 6-8 Hrs. | 4-6 Hrs. | Less than 4 Hrs. |

### 5.2.7 Statistical Analyses

#### 5.2.7.1 Positional Movement Demands

Descriptive statistics were presented as mean ± standard deviation (SD) for each practice throughout training camp, and Pearson's Correlation was completed to determine the magnitude and direction of covariance across all movement metrics used in this study. Following calculation of descriptive statistics, a one-way ANOVA was conducted for each movement metric to determine if the positions within the offensive and defensive teams had significant differences in each metric. To account for the unbalanced nature of this data, a post-hoc Tukey-Kramer test was used to establish significance across offensive and defensive positions. Statistically significant ($p<0.05$) differences within the defensive and offensive teams are listed in tables 13 and 14.

#### 5.2.7.2 Perceived Wellness

A series of random effects multi-level regressions, set at the individual and day level, were used to determine the differential effect of specific movement metrics from the previous day on perceived wellness ratings the following day. Categorical outcomes were used to determine less favorable responses (1-2), neutral responses (3), and more favorable responses (4-5) to account for the possibility of non-linear relationships with varying outcomes. Setting the data at the individual and day level allowed for the use of a multi-level model, which mitigates the nested structure of the data within a single day. Following the completion of the regressions, post-hoc testing including t-tests and Wald tests were used to determine relational significance between different categorical outcomes. Significance in all tests was measured at three levels: $p<0.05$, $p<0.01$ and $p<0.001$. The statistical means ± SD, regression coefficients, and 95% confidence intervals are presented in tables 15-20, and controlled for positional variation. All statistical analyses were performed using Stata Statistical/Data Analysis Software (Stata 14 for Windows, version 14.1; StataCorp, College Station, TX, USA).

## 5.3 Results

### 5.3.1 Positional Movement Demands

#### 5.3.1.1 Defense

The characteristics of movement patterns for defensive position groups are outlined in Table 13. Significant ($p<0.05$) differences were reported for several movement variables measured in the present study for defensive position groups. The DB position group accrued significantly ($p<0.05$) greater PL, total distance, low-intensity, high-intensity, and sprint running distance than all other defensive position groups. The LB position group demonstrated significantly ($p<0.05$) greater PL, total, low-intensity, medium-intensity, and high-intensity distance than both the DE and DT position groups. The DB position group accrued significantly ($p<0.05$) more acceleration and deceleration distance, in all zones of intensity, than all other defensive position groups. The LB position group demonstrated significantly ($p<0.05$) greater acceleration and deceleration distance, in all zones of intensity, than the DT and DE groups, except for max-intensity acceleration distance, when compared to DE.

**Table 13.** Defense positional movement profiles. Data are means ± standard deviations. $^{B}$Significantly different (p<0.05) for DB. $^{D}$ Significantly different (p<0.05) for DT. $^{E}$ Significantly different (p<0.05) for DE. All distance measures are represented as meters.

| Movement Variables | Defensive Back (DB) | Defensive Tackle (DT) | Defensive End (DE) | Linebacker (LB) |
|---|---|---|---|---|
| **Running Zone Distances (m)** | | | | |
| **Total Distance (m)** | 4530.3 ± 872.7 | 2777.5 ± 533.6 $^{B}$ | 2993.6 ± 417.4 $^{B}$ | 3794.9 ± 612.7 $^{BDE}$ |
| **Low Intensity Distance (m)** | 3568.3 ± 627.6 | 2518.7 ± 446.4$^{B}$ | 2637.0 ± 347.0$^{B}$ | 3039.2 ± 486.1 $^{BDE}$ |
| **Medium Intensity Distance (m)** | 680.0 ± 229.2 | 236.6 ± 129.6$^{B}$ | 324.6 ± 103.1$^{B}$ | 611.5 ± 163.6 $^{DE}$ |
| **High Intensity Distance (m)** | 239.3 ± 95.9 | 18.8 ± 22.7$^{B}$ | 28.3 ± 30.2$^{B}$ | 124.2 ± 56.8 $^{BDE}$ |
| **Sprinting Distance (m)** | 39.8 ± 32.2 | 1.7 ± 5.2$^{B}$ | 1.6 ± 4.4$^{B}$ | 17.6 ± 35.0 $^{BD}$ |
| **Player Load** | 467.4 ± 92.2 | 347.2 ± 65.2$^{B}$ | 356.5 ± 48.4$^{B}$ | 419.1 ± 63.5 $^{BDE}$ |
| **Low-Intensity Acceleration Distance** | 2157.7 ± 418.3 | 1316.2 ± 238.6$^{B}$ | 1378.6 ± 202.0$^{B}$ | 1725.5 ± 292.4 $^{BDE}$ |
| **Medium-Intensity Acceleration Distance** | 138.5 ± 34.6 | 66.2 ± 19.5$^{B}$ | 76.3 ± 14.5$^{B}$ | 120.7 ± 22.0 $^{BDE}$ |
| **High-Intensity Acceleration Distance** | 74.3 ± 18.1 | 36.2 ± 10.3$^{B}$ | 41.1 ± 6.6$^{B}$ | 64.6 ± 12.3 $^{BDE}$ |
| **Max-Intensity Acceleration Distance** | 114.2 ± 26.3 | 65.4 ± 20.9$^{B}$ | 93.7 ± 18.9 $^{BD}$ | 102.8 ± 22.3 $^{BD}$ |
| **Low-Intensity Deceleration Distance** | 1585.5 ± 330.6 | 970.7 ± 192.1$^{B}$ | 1064.3 ± 172.6$^{B}$ | 1373.3 ± 235.6 $^{BDE}$ |
| **Medium-Intensity Deceleration Distance** | 114.8 ± 28.4 | 48.0 ± 17.9$^{B}$ | 61.7 ± 12.0$^{B}$ | 96.1 ± 20.2$^{BDE}$ |
| **High-Intensity Deceleration Distance** | 45.4 ± 12.5 | 14.2 ± 6.5$^{B}$ | 18.6 ± 5.1$^{B}$ | 33.4 ± 8.6$^{BDE}$ |
| **Max-Intensity Deceleration Distance** | 37.3 ± 11.9 | 7.1 ± 3.8 $^{B}$ | 10.5 ± 3.6 $^{B}$ | 25.0 ± 9.0 $^{BDE}$ |

#### 5.3.1.2 Offense

The characteristics of movement patterns for offensive position groups are outlined in Table 14. Significant ($p<0.05$) differences were reported for several movement variables measured in the present study for offensive position groups. The WR position group demonstrated significantly ($p<0.05$) greater total, medium-intensity, high-intensity, and sprint distance than all other offensive position groups, and significantly ($p<0.05$) higher PL than all offensive groups, except for the QB. Additionally, the WR group achieved significantly ($p<0.05$) greater low-, medium, and high-intensity acceleration and deceleration distance than all other offensive position groups, while the RB group demonstrated significantly ($P<0.05$) higher high-intensity and max-intensity deceleration distance than the QB, TE, and OL groups. The OL position group accrued significantly ($p<0.05$) less total and high-intensity distance, and significantly ($p<0.05$) less acceleration and deceleration distance, at all intensities, than every other offensive position group.

**Table 14.** Offense positional movement profiles. Data are means ± standard deviations. $^{W}$ Significantly different ($p<0.05$) for WR. $^{R}$ Significantly different ($p<0.05$) for RB. $^{Q}$ Significantly different ($p<0.05$) for QB. $^{T}$ Significantly different ($p<0.05$) for TE. All distance measures are represented as meters.

| Movement Variables | Wide Receiver (WR) | Running Back (RB) | Quarterback (QB) | Tight End (TE) | Offensive Linemen (OL) |
|---|---|---|---|---|---|
| **Running Zone Distances (m)** | | | | | |
| **Total Distance** | 4233.0 ± 839.3 | 3331.5 ± 625.3$^{W}$ | 3533.3 ± 497.6$^{W}$ | 3386.6 ± 783.7$^{W}$ | 2556.7 ± 501.2$^{WQRT}$ |
| **Low-Intensity Distance** | 3240.1 ± 627.2 | 2609.3 ± 510.3$^{W}$ | 3101.5 ± 440.1$^{R}$ | 2792.3 ± 595.8$^{W}$ | 2442.7 ± 465.8$^{WQT}$ |
| **Medium-Intensity Distance** | 596.3 ± 156.3 | 486.4 ± 105.3$^{W}$ | 332.8 ± 140.1$^{WR}$ | 442.6 ± 188.1$^{W}$ | 106.5 ± 57.7$^{WQRT}$ |
| **High-Intensity Distance** | 342.8 ± 115.1 | 210.3 ± 64.4$^{W}$ | 82.7 ± 51.8$^{WR}$ | 145.7 ± 83.2$^{WQR}$ | 5.7 ± 12.2$^{WQRT}$ |
| **Sprint Distance** | 50.8 ± 44.0 | 22.7 ± 23.0$^{W}$ | 13.5 ± 19.0$^{W}$ | 3.7 ± 7.5$^{WR}$ | 0.0 ± 0.2$^{WR}$ |
| **Player Load (AU)** | 432.7 ± 79.7 | 358.6 ± 68.7$^{W}$ | 376.6 ± 55.6 | 371.8 ± 78.0$^{W}$ | 330.3 ± 66.9$^{WT}$ |
| **Low-Intensity Acceleration Distance** | 1959.0 ± 402.5 | 1520.5 ± 301.2$^{W}$ | 1692.6 ± 247.6$^{W}$ | 1553.0 ± 352.7$^{W}$ | 1169.6 ± 236.0$^{WQRT}$ |
| **Medium-Intensity Acceleration Distance** | 122.3 ± 28.2 | 99.0 ± 23.5$^{W}$ | 88.0 ± 18.4$^{W}$ | 94.8 ± 29.0$^{W}$ | 64.3 ± 15.8$^{WQRT}$ |
| **High-Intensity Acceleration Distance** | 71.8 ± 17.0 | 61.5 ± 16.2$^{W}$ | 49.4 ± 9.9$^{W}$ | 51.2 ± 15.3$^{WR}$ | 29.5 ± 6.7$^{WQRT}$ |
| **Max-Intensity Acceleration Distance** | 127.3 ± 27.9 | 113.5 ± 30.3 | 83.7 ± 20.9$^{WR}$ | 100.4 ± 31.7$^{W}$ | 51.5 ± 14.8$^{WQRT}$ |
| **Low-Intensity Deceleration Distance** | 1509.2 ± 331.3 | 1128.5 ± 226.2$^{W}$ | 1213.4 ± 188.0$^{W}$ | 1203.1 ± 301.6$^{W}$ | 875.2 ± 175.3$^{WQRT}$ |
| **Medium-Intensity Deceleration Distance** | 115.4 ± 27.9 | 87.0 ± 18.8$^{W}$ | 68.5 ± 20.1$^{W}$ | 82.3 ± 28.7$^{W}$ | 42.0 ± 12.6$^{WQRT}$ |
| **High-Intensity Deceleration Distance** | 45.2 ± 12.8 | 39.0 ± 9.4$^{W}$ | 21.4 ± 6.9$^{WR}$ | 28.9 ± 11.0$^{WR}$ | 11.3 ± 4.1$^{WQRT}$ |
| **Max-Intensity Deceleration Distance** | 40.0 ± 13.2 | 36.0 ± 11.1 | 14.5 ± 5.7$^{WR}$ | 22.1 ± 9.6$^{WR}$ | 5.6 ± 2.8$^{WQRT}$ |

### 5.3.2 Perceived Wellness

#### 5.3.2.1 Perceived Fatigue

Significant ($p<0.001$) differences in PL and total distance resulting from practice on the preceding day, were demonstrated in players who rated their level of fatigue a 1 or 2, compared to those who selected 3, 4, or 5. Significant differences in PL ($p<0.001$) and total distance ($p<0.001$) were also demonstrated in those who rated fatigue a 3 compared to those who rated fatigue a 4 or 5. Individuals who rated their perceived fatigue a 1 or 2 covered significantly ($p<0.01$) more acceleration and deceleration distance at all intensities than those who rated their fatigue as a 3. Similarly, significantly ($p<0.01$) more acceleration and deceleration distance at all intensities was accrued during the preceding practice day by those who rated their perceived fatigue a 3 when compared to those who rated it a 4 or 5 (Table 15).

**Table 15. Ratings of Perceived Fatigue:** ***Line 1: Statistical Mean ± Standard Deviation***
*Line 2: Regression Coefficient with Lower and Upper limits of 95% Confidence Interval (Controlling for positional variation; indexed against a score of 1 or 2)*
[A] Significantly different (p<0.05) for 1 and 2. [B] Significantly different (p<0.05) for 3. All distance measures are represented as meters.

| Perceived Fatigue | | | |
|---|---|---|---|
| **Movement Variables** | **1 or 2** | **3** | **4 or 5** |
| **Total Distance** | **4908.9 ± 1826.1** | **4254.3 ± 1687.0 [A]**<br>*-715.2(-1120.5,-309.9)* | **3624.2 ± 1161.9 [AB]**<br>*-1313.1 (-1703.0,-923.2)* |
| **Low-Intensity Distance** | **3973.7 ± 1328.7** | **3470.0 ± 1244.4 [A]**<br>*-564.9 (-879.1,-250.6)* | **3090.7 ± 897.3 [AB]**<br>*-1010.6 (-1314.0,-707.2)* |
| **Medium-Intensity Distance** | **700.5 ± 374.3** | **552.2 ± 340.3 [A]**<br>*-125.6 (-191.8,-59.4)* | **394.9 ± 272.7 [AB]**<br>*-224.9 (-288.9,-161.2)* |
| **High-Intensity Distance** | **206.8 ± 198.6** | **200.2 ± 180.6**<br>*-23.0 (-54.6,8.6)* | **121.4 ± 133.4 [AB]**<br>*-62.9 (-101.9,-23.9)* |
| **Sprinting Distance** | **24.6 ± 40.1** | **28.8 ± 43.4**<br>*1.3 (-7.7,10.2)* | **14.7 ± 24.1**<br>*-7.2 (-14.5,0.1)* |
| **Player Load** | **546.4 ± 199.2** | **467.9 ± 165.1 [A]**<br>*-83.8 (-128.5,-39.1)* | **397.9 ± 117.4 [AB]**<br>*-154.3 (-197.1,-111.6)* |
| **Low-Intensity Accel. Distance** | **2285.8 ± 853.4** | **1977.8 ± 799.2 [A]**<br>*-342.8 (-531.5,-154.0)* | **1674.1 ± 549.6 [AB]**<br>*-638.0 (-822.6,-453.4)* |
| **Medium-Intensity Accel. Distance** | **143.8 ± 66.0** | **122.7 ± 58.1 [A]**<br>*-22.1 (-36.1,-8.1)* | **99.3 ± 42.0 [AB]**<br>*-41.8 (-55.6,-28.0)* |
| **High-Intensity Accel. Distance** | **80.0 ± 36.7** | **67.6 ± 32.6 [A]**<br>*-12.7 (-19.9,-5.5)* | **52.2 ± 23.1[AB]**<br>*-23.9 (-30.9,-17.0)* |
| **Max-Intensity Accel. Distance** | **139.2 ± 57.3** | **117.5 ± 54.3 [A]**<br>*-20.7 (-32.6,-8.8)* | **89.4 ± 36.3 [AB]**<br>*-41.1 (-52.8,-29.4)* |
| **Low-Intensity Decel. Distance** | **1747.8 ± 664.3** | **1502.1 ± 622.8 [A]**<br>*-257.3 (-407.1,-107.4)* | **1252.4 ± 441.9 [AB]**<br>*-501.7 (-643.5,-359.8)* |
| **Medium-Intensity Decel. Distance** | **119.0 ± 56.4** | **102.6 ± 53.7 [A]**<br>*-17.5 (-28.4,-6.6)* | **80.3 ± 40.1 [AB]**<br>*-34.0 (-45.0,-23.1)* |
| **High-Intensity Decel. Distance** | **43.4 ± 24.1** | **38.1 ± 22.8 [A]**<br>*-6.8 (-11.5,-2.0)* | **28.0 ± 17.3 [AB]**<br>*-12.9 (-17.8,-8.0)* |
| **Max-Intensity Decel. Distance** | **35.2 ± 24.8** | **30.4 ± 21.3 [A]**<br>*-6.8 (-11.3,-2.3)* | **20.1 ± 15.2 [AB]**<br>*-12.1 (-16.8,-7.3)* |

#### 5.3.2.2 Perceived Soreness

Significant ($p<0.001$) differences in total distance resulting from practice on the preceding day were demonstrated in players who rated their level of soreness a 1 or 2, compared to those who selected 3, 4, or 5, along with significant ($p<0.05$) differences in PL in those who rated perceived soreness a 1 or 2, vs. 3, vs. a 4 or 5. Significantly ($p<0.05$) more acceleration and deceleration distance was reported for all intensities for those who rated perceived soreness a 1 or 2 when compared to those who rated it a 3, 4, or 5. Additionally, significantly ($p<0.05$) less maximal-acceleration distance was covered by those who rated their level of soreness a 4 or 5 compared to those who rated it a 1 or 2, or a 3. Significantly ($p<0.001$) less low-, medium-, and high-intensity running distance was covered in those who rated perceived soreness a 3, 4, or 5 compared to individuals who rated perceived soreness a 1 or 2 (Table 16).

**Table 16. Ratings of Perceived Soreness:** ***Line 1: Statistical Mean ± Standard Deviation***
*Line 2: Regression Coefficient with Lower and Upper limits of 95% Confidence Interval (Controlling for positional variation; indexed against a score of 1 or 2)*
$^{A}$ Significantly different ($p < 0.05$) for 1 and 2. $^{B}$ Significantly different ($p < 0.05$) for 3. All distance measures are represented as meters.

| Perceived Soreness | | | |
|---|---|---|---|
| **Movement Variables** | **1 or 2** | **3** | **4 or 5** |
| **Total Distance** | **4655.1 ± 1864.1** | **4169.8 ± 1514.1 $^{A}$**<br>*-917.5(-1227.5,-607.5)* | **3350.8 ± 1064.0 $^{A}$**<br>*-1214.9(-1579.9,-850.0)* |
| **Low-Intensity Distance** | **3792.8 ± 1364.1** | **3410.7 ± 1122.7 $^{A}$**<br>*-692.0 (-938.6,-445.3)* | **2886.8 ± 824.9 $^{AB}$**<br>*-939.8 (-1231.1,-648.5)* |
| **Medium-Intensity Distance** | **626.8 ± 385.8** | **539.5 ± 311.1 $^{A}$**<br>*-156.7 (-210.1,-103.2)* | **343.7 ± 253.1 $^{A}$**<br>*-188.9 (-250.8,-127.0)* |
| **High-Intensity Distance** | **205.4 ± 195.2** | **190.2 ± 166.2 $^{A}$**<br>*-53.5 (-77.3,-29.6)* | **104.4 ± 138.7 $^{A}$**<br>*-67.7 (-97.7,-37.7)* |
| **Sprinting Distance** | **27.0 ± 43.6** | **26.5 ± 38.8**<br>*-7.0 (-14.3,0.2)* | **13.6 ± 26.4**<br>*-7.0 (-14.3,0.3)* |
| **Player Load** | **521.7 ± 196.6** | **450.3 ± 143.2 $^{A}$**<br>*-105.8 (-141.3,-70.4)* | **376.2 ±110.7 $^{AB}$**<br>*-142.0 (-182.1,-101.9)* |
| **Low-Intensity Accel. Distance** | **2167.4 ± 864.0** | **1936.4 ± 730.0 $^{A}$**<br>*-439.1 (-580.4,-297.7)* | **1544.1 ± 501.8 $^{AB}$**<br>*-577.9 (-742.3,-413.5)* |
| **Medium-Intensity Accel. Distance** | **136.2 ± 66.8** | **119.1 ± 50.9 $^{A}$**<br>*-31.5 (-42.0,-21.1)* | **90.2 ± 39.5 $^{A}$**<br>*-39.2 (-51.7,-26.7)* |
| **High-Intensity Accel. Distance** | **75.0 ± 37.2** | **65.5 ± 28.8 $^{A}$**<br>*-16.7 (-22.8,-10.6)* | **47.1 ± 21.7 $^{A}$**<br>*-21.9 (-28.8,-15.1)* |
| **Max-Intensity Accel. Distance** | **128.7 ± 60.5** | **114.1 ± 47.9 $^{A}$**<br>*-28.3 (-38.4,-18.1)* | **82.7 ± 35.8 $^{AB}$**<br>*-39.3 (-50.4,-28.2)* |
| **Low-Intensity Decel. Distance** | **1652.0 ± 683.4** | **1456.7 ± 559.8 $^{A}$**<br>*-338.2 (-445.6,-230.7)* | **1157.6 ± 417.4 $^{AB}$**<br>*-465.4 (-596.3,-334.5)* |
| **Medium-Intensity Decel. Distance** | **111.7 ± 59.8** | **100.6 ± 47.3 $^{A}$**<br>*-24.0 (-32.8,-15.2)* | **72.0 ± 38.7 $^{A}$**<br>*-31.6 (-42.7,-20.5)* |
| **High-Intensity Decel. Distance** | **41.3 ± 25.4** | **36.8 ± 20.2 $^{A}$**<br>*-10.8 (-14.3,-7.3)* | **25.1 ± 16.4 $^{A}$**<br>*-12.3 (-16.3,-8.2)* |
| **Max-Intensity Decel. Distance** | **32.7 ± 24.4** | **29.4 ± 23.2 $^{A}$**<br>*-8.9 (-12.5,-5.2)* | **17.6 ± 15.3 $^{A}$**<br>*-10.5 (-14.4,-6.6)* |

#### 5.3.2.3 Perceived Sleep Quantity

Total distance was significantly ($p<0.05$) lower for those who rated their sleep quantity a 4 or 5 when compared to those who rated sleep quantity a 1, 2, or 3. Players loads were significantly ($p<0.05$) higher for individuals whose perceived sleep quantity was a 1 or 2 compared to 3, and those whose sleep quantity was a 3 compared to a 4 or 5. Significantly ($p<0.05$) greater high-intensity acceleration and deceleration distance, and max-intensity acceleration distance was reported for those who rated sleep quantity a 1 or 2 compared to those who rated it a 3, and for those who rated sleep quantity and 3 compared those whose ratings were a 4 or 5. Significantly ($p<0.05$) more max-intensity deceleration distance was demonstrated for those who rated sleep quantity a 1 or 2 compared to those rating it a 3, 4, or 5 (Table 17). No significant ($p<0.05$) differences in GPS and IA variables related to perceived sleep quality existed (Table 18).

**Table 17. Ratings of Perceived Sleep Quantity:** ***Line 1: Statistical Mean ± Standard Deviation***

*Line 2: Regression Coefficient with Lower and Upper limits of 95% Confidence Interval (Controlling for positional variation; indexed against a score of 1 or 2)*

[A] Significantly different ($p < 0.05$) for 1 and 2. [B] Significantly different ($p < 0.05$) for 3. All distance measures are represented as meters.

| Perceived Sleep Quantity | | | |
|---|---|---|---|
| **Movement Variables** | **1 or 2** | **3** | **4 or 5** |
| **Total Distance** | **4755.3 ± 2002.0** | **4243.1 ± 1551.7**<br>*-501.1(-1053.4, 51.1)* | **3939.2 ± 1566.6** [AB]<br>*-845.5(-1401.8,-289.2)* |
| **Low-Intensity Distance** | **3815.2 ± 1424.8** | **3506.9 ± 1169.0**<br>*-341.3 (-752.1, 69.6)* | **3255.4 ± 1147.7** [AB]<br>-614.0(-1029.4,-198.7) |
| **Medium-Intensity Distance** | **703.4 ± 431.2** | **540.2 ± 326.2**<br>*-103.3 (-208.4, 1.7)* | **467.6 ± 306.2** [AB]<br>*-155.9 (-261.6,-50.3)* |
| **High-Intensity Distance** | **203.0 ± 190.3** | **171.8 ± 163.0**<br>*-36.5 (-81.5, 8.5)* | **186.7 ± 189.1** [A]<br>*-48.2 (-94.0,-2.5)* |
| **Sprinting Distance** | **30.5 ± 44.0** | **21.2 ± 36.6**<br>*-6.8 (-14.8, 1.1)* | **26.8 ± 40.4**<br>*-8.6 (-17.2, 0.1)* |
| **Player Load** | **534.1 ± 208.4** | **465.3 ± 154.7** [A]<br>*-59.8 (-115.8,-3.8)* | **433.2 ± 159.3** [AB]<br>*-101.3 (-159.3, -43.3)* |
| **Low-Intensity Accel. Distance** | **2214.5 ± 942.8** | **1972.9 ± 731.2**<br>*-234.2 (-504.7, 36.2)* | **1823.4 ± 743.5** [AB]<br>-404.3 (-674.7,-133.9) |
| **Medium-Intensity Accel. Distance** | **144.1 ± 75.1** | **120.2 ± 53.1** [A]<br>*-19.7 (-38.7,-0.7)* | **111.2 ± 53.2** [A]<br>*-28.9 (-48.5,-9.4)* |
| **High-Intensity Accel. Distance** | **77.5 ± 37.7** | **66.0 ± 30.5** [A]<br>*-9.6 (-19.8,-0.2)* | **61.0 ± 31.1** [AB]<br>*-16.0 (-25.9,-6.1)* |
| **Max-Intensity Accel. Distance** | **126.0 ± 57.1** | **116.2 ± 50.0** [A]<br>*-15.6 (-30.7,-0.4)* | **106.6 ± 55.9** [AB]<br>*-28.3 (-44.0,-12.5)* |
| **Low-Intensity Decel. Distance** | **1692.8 ± 728.9** | **1504.8 ± 572.5**<br>*-173.8 (-377.2, 29.6)* | **1363.4 ± 585.7** [AB]<br>*-330.8 (-534.7,-126.9)* |
| **Medium-Intensity Decel. Distance** | **112.8 ± 59.0** | **100.5 ± 48.8**<br>*-12.0 (25.2,1.2)* | **93.8 ± 54.5** [AB]<br>*-21.1 (-35.5,-6.7)* |
| **High-Intensity Decel. Distance** | **42.4 ± 24.4** | **36.3 ± 21.1** [A]<br>*-5.7 (-11.1,-0.3)* | **34.3 ± 22.9** [AB]<br>*-9.0 (-14.9,-3.0)* |
| **Max-Intensity Decel. Distance** | **35.4 ± 24.4** | **27.3 ± 19.5** [A]<br>*-7.1 (-12.6,-1.6)* | **27.8 ± 21.8** [A]<br>*-8.7 (-14.3,-3.1)* |

**Table 18. Ratings of Perceived Sleep Quality:** ***Line 1: Statistical Mean ± Standard Deviation***

*Line 2: Regression Coefficient with Lower and Upper limits of 95% Confidence Interval (Controlling for positional variation; indexed against a score of 1 or 2)*

[A] Significantly different ($p < 0.05$) for 1 and 2. [B] Significantly different ($p < 0.05$) for 3. All distance measures are represented as meters.

| Perceived Sleep Quality | | | |
|---|---|---|---|
| **Movement Variables** | **1 or 2** | **3** | **4 or 5** |
| **Total Distance** | **4463.0 ± 1841.1** | **4441.3 ± 1853.8**<br>*-475.7(-1137.1,185.7)* | **4125.3 ± 1564.0**<br>*-459.4(-1108.9, 190.1)* |
| **Low-Intensity Distance** | **3689.9 ± 1313.4** | **3567.1 ± 1324.4**<br>*-393.2 (-883.9, 97.5)* | **3415.5 ± 1172.2**<br>*-335.8 (-817.9, 146.4)* |
| **Medium-Intensity Distance** | **583.1 ± 366.5** | **636.0 ± 386.0**<br>*-59.5 (-182.6, 63.7)* | **507.4 ± 325.8**<br>*-84.5 (-199.1, 30.2)* |
| **High-Intensity Distance** | **158.8 ± 207.3** | **206.4 ± 189.6**<br>*-9.9 (-54.0, 34.2)* | **176.6 ± 169.6**<br>*-24.5 (-73.6, 24.6)* |
| **Sprinting Distance** | **28.1 ± 60.2** | **28.8 ± 39.5**<br>*-12.0 (-31.6, 7.6)* | **23.0 ± 36.7**<br>*-12.8 (-32.3, 6.7)* |
| **Player Load** | **498.7 ± 183.9** | **484.5 ± 193.3**<br>*-52.1 (-125.1, 21.0)* | **455.5 ± 158.4**<br>*-52.1 (-119.1, 14.9)* |
| **Low-Intensity Accel. Distance** | **2075.3 ± 826.1** | **2072.3 ± 880.5**<br>*-220.9 (-511.6, 69.7)* | **1912.8 ± 741.3**<br>*-217.1 (-508.4, 74.2)* |
| **Medium-Intensity Accel. Distance** | **124.9 ± 63.7** | **132.8 ± 67.2**<br>*-11.6 (-34.9, 11.7)* | **116.7 ± 53.2**<br>*-12.4 (-34.3, 9.4)* |
| **High-Intensity Accel. Distance** | **69.9 ± 36.6** | **71.8 ± 35.0**<br>*-8.6 (-21.4, 4.2)* | **63.9 ± 31.3**<br>*-9.1 (-20.3, 2.2)* |
| **Max-Intensity Accel. Distance** | **123.1 ± 60.1** | **116.8 ± 53.7**<br>*-15.4 (-37.2, 6.4)* | **112.8 ± 52.9**<br>*-15.4 (-35.4, 4.7)* |
| **Low-Intensity Decel. Distance** | **1592.8 ± 714.3** | **1571.0 ± 675.9**<br>*-174.1 (-431.3, 83.0)* | **1488.4 ± 579.3**<br>*-178.1 (-431.4, 75.1)* |
| **Medium-Intensity Decel. Distance** | **104.1 ± 58.9** | **108.3 ± 54.3**<br>*-11.4 (-30.1, 7.2)* | **97.2 ± 51.5**<br>-12.3 (-30.0, 5.3) |
| **High-Intensity Decel. Distance** | **35.8 ± 24.4** | **41.2 ± 23.6**<br>*-2.4 (-9.7, 4.8)* | **35.3 ± 21.7**<br>*-3.5 (-10.6, 3.5)* |
| **Max-Intensity Decel. Distance** | **27.2 ± 21.7** | **33.4 ± 22.0**<br>*-2.9 (-9.9, 4.1)* | **27.4 ± 21.8**<br>*-4.3 (-10.7, 2.2)* |

#### 5.3.2.4 Perceived Stress and Mood

No GPS and IA derived variables demonstrated significant differences when examining those who rated their stress level a 1 or 2 compared to those who rated perceived stress a 3. However, individuals who rated stress a 4 or 5 had significantly ($p<0.01$) lower PL, in addition to significantly ($p<0.01$) less total distance, low-, medium-, and high-intensity distance than those who rated perceived stress a 3. Significant ($p<0.05$) differences were reported for all intensities of acceleration and deceleration distance, with individuals who rated perceived stress a 4 or 5 covering less distance in all zones of intensity than those rating perceived stress a 3, and significantly ($p<0.05$) less high- and max-intensity deceleration distance in those who rated perceived stress a 4 or 5 compared to those whose ratings were a 1, 2, or 3 (Table 19). Individuals who rated mood a 4 or 5 accrued significantly ($p<0.05$) less PL, total distance and max-intensity deceleration distance than those who rated their perceived mood a 1 or 2 (Table 20).

**Table 19. Ratings of Perceived Stress:** ***Line 1: Statistical Mean ± Standard Deviation***
*Line 2: Regression Coefficient with Lower and Upper limits of 95% Confidence Interval (Controlling for positional variation; indexed against a score of 1 or 2)*
[A] Significantly different ($p < 0.05$) for 1 and 2. [B] Significantly different ($p < 0.05$) for 3. All distance measures are represented as meters.

| Perceived Stress | | | |
|---|---|---|---|
| **Movement Variables** | **1 or 2** | **3** | **4 or 5** |
| **Total Distance (m)** | **4370.0 ± 1493.6** | **4620.5 ± 1851.9**<br>*-172.9(-1126.5,780.6)* | **3855.0 ± 1391.3** [B]<br>*-773.4(-1691.4,144.6)* |
| **Low-Intensity Distance** | **3613.5 ± 1231.0** | **3724.3 ± 1363.8**<br>*-154.0(-942.9, 635.0)* | **3231.3 ± 1024.8** [B]<br>*-604.2(-1372.1,163.7)* |
| **Medium-Intensity Distance** | **622.1 ± 250.3** | **646.6 ± 365.6**<br>*-39.3 (-177.8, 99.3)* | **440.1 ± 306.6** [AB]<br>*-131.3 (-260.2,-2.4)* |
| **High-Intensity Distance** | **119.6 ± 107.2** | **218.6 ± 190.7**<br>*16.3 (-22.7, -55.3)* | **157.7 ± 164.8** [B]<br>*-29.6 (-64.7, 5.5)* |
| **Sprinting Distance** | **11.6 ± 22.5** | **27.9 ± 44.0**<br>*4.3 (-5,1, 13.8)* | **23.2 ± 36.0**<br>*-3.2 (-15.5, 9.1)* |
| **Player Load** | **498.9 ± 174.3** | **500.5 ± 189.3**<br>-32.8 (-137.9, 72.3) | **430.3 ± 140.0** [B]<br>*-98.1 (-199.5, 3.4)* |
| **Low-Intensity Accel. Distance** | **2017.2 ± 700.4** | **2151.5 ± 875.5**<br>*-68.3 (-513.2, 376.5)* | **1786.9 ± 656.8** [B]<br>*-353.0 (-782.3, 76.2)* |
| **Medium-Intensity Accel. Distance** | **128.4 ± 49.9** | **135.0 ± 65.0**<br>*-6.8 (-37.1, 23.6)* | **107.7 ± 48.8** [B]<br>*-25.4 (-54.6, 3.8)* |
| **High-Intensity Accel. Distance** | **68.6 ± 28.6** | **74.3 ± 34.8**<br>*-2.0 (-18.2, 14.2)* | **58.7 ± 29.3** [B]<br>*-12.6 (-28.6, 3.4)* |
| **Max-Intensity Accel. Distance** | **118.0 ± 47.7** | **128.7 ± 55.0**<br>*-6.0 (-31.7, 19.7)* | **101.8 ± 49.9** [B]<br>*-25.2 (-50.8, 0.5)* |
| **Low-Intensity Decel. Distance** | **1574.9 ± 574.3** | **1639.0 ± 679.0**<br>*-78.3 (-423.4, 266.8)* | **1343.0 ± 520.4** [B]<br>*-306.2 (-640.2, 27.8)* |
| **Medium-Intensity Decel. Distance** | **99.0 ± 40.1** | **114.2 ± 56.3**<br>*-0.9 (-25.5, 23.6)* | **88.1 ± 47.8** [B]<br>*-16.3 (-39.8, 7.1)* |
| **High-Intensity Decel. Distance** | **36.3 ± 17.4** | **42.2 ± 23.4**<br>*-2.4 (-10.6, 5.9)* | **31.8 ± 20.9** [AB]<br>*-9.1 (-17.5,-0.7)* |
| **Max-Intensity Decel. Distance** | **27.2 ± 17.8** | **33.0 ± 21.6**<br>*-2.1 (-9.9, 5.6)* | **25.2 ± 20.7** [AB]<br>*-7.7 (-15.4, -0.1)* |

**Table 20. Ratings of Perceived Mood: *Line 1: Statistical Mean ± Standard Deviation***
*Line 2: Regression Coefficient with Lower and Upper limits of 95% Confidence Interval (Controlling for positional variation; indexed against a score of 1 or 2)*
[A] Significantly different ($p < 0.05$) for 1 and 2. [B] Significantly different ($p < 0.05$) for 3. All distance measures are represented as meters.

| Perceived Mood | | | |
|---|---|---|---|
| **Movement Variables** | **1 or 2** | **3** | **4 or 5** |
| **Total Distance (m)** | **4361.7 ± 1870.6** | **4958.8 ± 1839.8**<br>*-315.5 (-871.3, 240.4)* | **4080.1 ± 1570.1** [A]<br>*-616.7(-1182.6,-50.8)* |
| **Low-Intensity Distance** | **3623.4 ± 1390.7** | **3941.3 ± 1360.9**<br>*-263.8(-668.8, 141.3)* | **3375.3 ± 1159.7** [A]<br>-507.5 (-923.7,-91.3) |
| **Medium-Intensity Distance** | **575.9 ± 341.9** | **706.4 ± 322.9**<br>*-59.8 (-198.4, 78.8)* | **509.2 ± 342.0**<br>*-94.1 (-221.1, 33.0)* |
| **High-Intensity Distance** | **141.0 ± 201.7** | **265.0 ± 210.9**<br>*13.6 (-19.6, 46.7)* | **170.8 ± 164.8**<br>*-4.1 (-40.6, 32.3)* |
| **Sprinting Distance** | **18.3 ± 53.6** | **42.8 ± 48.5**<br>*5.5 (-5.1, 16.2)* | **21.9 ± 35.4**<br>*-3.1 (-15.9, 9.8)* |
| **Player Load** | **504.5 ± 197.4** | **532.0 ± 195.0**<br>*-41.8 (-103.5, 19.9)* | **450.4 ± 158.4** [A]<br>*-81.2 (-136.2,-26.1)* |
| **Low-Intensity Accel. Distance** | **2026.4 ± 838.4** | **2326.7 ± 882.3**<br>*-140.4 (-396.0, 115.1)* | **1890.9 ± 741.2** [A]<br>*-294.8 (-551.5,-38.0)* |
| **Medium-Intensity Accel. Distance** | **122.7 ± 64.3** | **145.6 ± 62.1**<br>*-11.6 (-30.5, 7.3)* | **116.4 ± 55.7**<br>*-16.9 (-34.3, 0.4)* |
| **High-Intensity Accel. Distance** | **68.4 ± 37.2** | **81.4 ± 34.5**<br>*-5.5 (-15.8, 4.7)* | **63.2 ± 31.3**<br>*-10.2 (-20.4, 0.0)* |
| **Max-Intensity Accel. Distance** | **114.6 ± 63.9** | **137.8 ± 55.4**<br>*-5.5 (-23.1, 12.2)* | **110.4 ± 51.5**<br>*-15.3 (-33.3, 2.5)* |
| **Low-Intensity Decel. Distance** | **1572.1 ± 731.2** | **1751.0 ± 659.4**<br>*-120.0 (-351.3, 111.4)* | **1433.1 ± 583.1**<br>*-236.1 (-474.9, 2.8)* |
| **Medium-Intensity Decel. Distance** | **96.0 ± 56.8** | **125.7 ± 55.9**<br>*-2.5 (-18.9, 13.9)* | **96.0 ± 50.8**<br>*-9.3 (-26.1, 7.5)* |
| **High-Intensity Decel. Distance** | **36.0 ± 24.2** | **47.0 ± 23.8**<br>*-3.2 (-10.5, 4.1)* | **34.9 ± 21.6**<br>*-5.2 (-11.9, 1.6)* |
| **Max-Intensity Decel. Distance** | **29.7 ± 23.2** | **37.7 ± 22.0**<br>*-5.0 (-10.7, 0.6)* | **27.1 ± 20.6** [A]<br>*-6.1 (-11.1, -1.2)* |

## 5.4 Discussion

The present study examined 1) the positional movement demands associated with pre-season training camp practices in NCAA division I college football players using portable GPS and IA technology and 2) assessed the daily perceived wellness associated with pre-season training camp utilizing a modified questionnaire to determine if GPS-derived measures influence perceived ratings of wellness. The results of the present study confirm our hypothesis that 1) significant ($p<0.05$) differences exist in positional movement demands during pre-season training camp in NCAA division I college football players, and 2) significant ($p<0.05$) differences in GPS and IA training loads exist in the preceding day's practice for those athletes who rated their perceived wellness less favorable the following day.

The present study found significant ($p<0.05$) differences in total distance traveled between position groups within both offensive and defensive teams during pre-season training camp practice. In addition to differences in total distance covered by the WR, DB, and LB position groups, the present study demonstrated significant ($p<0.05$) differences in high-intensity and sprint distance covered by WR and DB compared to all other positions on their respective offensive or defensive teams. Similar positional differences in division I college football players participating in pre-season training camp were reported by DeMartini et. al (56). An examination (235) of division I college football players participating in competitive games demonstrated significant differences in moderate- (10.0 – 16.0 $km \cdot h^{-1}$), high-intensity (16.1 – 23.0 $km \cdot h^{-1}$), and sprint distances (> 23.0 $km \cdot h^{-1}$) when comparing WR and DB and LB to their offensive and defensive counterparts, which supports the results of the present study, requiring increased running volumes of these positions as a means of preparing for the volumes and intensities associated with pre-season camp and subsequent competitive performance. The positional differences associated with running volumes and intensities observed in the present study may be attributed to position-specific offensive and defensive requirements during training and competition. The primary responsibility of the OL group is to block defensive players, restricting them from tackling the ball carrier. Quick bursts of acceleration, deceleration, and changes of direction, frequently occurring at or near the line of scrimmage, are associated with this tactical responsibility and limit the distance traveled and the velocity achieved during each play. Similarly, players in the DT and DE position groups accelerate short distances and perform rapid change of direction movements prior to, and immediately following, physical contact with the opposing OL. Unlike their offensive and defensive counterparts who are required to travel greater distances prior to engaging an opponent, the OL, DT, and DE positions commence play approximately one meter away from their opponent, thereby limiting subsequent running distances. The differences in high-intensity distance demonstrated by the RB group compared to the OL, QB and TE groups in the present study, may be attributed to the diverse tactical requirements associated with the positional demands of the RB group, including carrying the ball, running pass routes, and blocking to provide protection for the QB on passing plays. The unique physical requirements of the LB position, including engaging OL and TE prior to tackling the ball carrier on running plays, similar to the DT and DE groups, and defending the RB, TE, and WR on passing plays, similar to DB group, are associated with specific movement profile characteristics of this position. The WR position group is required to repeatedly run routes on passing plays, serving as a primary or secondary target, and often on running plays, serving as a decoy to the opposing DB. These position-specific requirements provide explanation for the increased total, high-intensity, and sprint distance associated with the WR position. The DB position is primarily responsible for defending the WR on passing routes, in addition to providing secondary support on running plays, often requiring high-speed pursuit of the ball carrier. Consequently, the DB position is involved in repeated bouts of running, which is reflected in the present study with more total and high-intensity distance than all other defensive position groups.

An examination of the positional acceleration and deceleration distances revealed significant ($p<0.05$) differences at nearly every intensity, for the DB and LB group compared to other defensive positions. The results of the present study are consistent with the work of Wellman et. al. (235) who reported a significantly ($p<0.05$) greater number of maximal acceleration and deceleration and high-intensity acceleration efforts for the DB position group than all other defensive position groups, and significantly more for the LB group when compared to the DT and DE position group. The results of the present study, along with previous investigations (235) in NCAA division I football, highlight distinct positional movement characteristics within the defensive team. Offensively, the WR position group accumulated significantly ($p<0.05$) greater low-, medium- and high-intensity acceleration and deceleration distance than all other offensive groups. The results of the present study are supported by previous research (235) examining positional movement demands in NCAA division I football players which reported significant ($p<0.05$) differences in acceleration and deceleration efforts for the WR group compared to other offensive position groups. Collectively, these results highlight the importance of developing and implementing a well-planned training program in the weeks preceding the start of training camp that adequately prepares athletes for the unique positional movement demands associated with pre-season practices. Currently, there is an absence of studies that have investigated the performance demands of NCAA division I football, and the movement demands associated with pre-season training camps are unknown. Accordingly, the present study provides a novel examination of performance related research in NCAA division I football that may be used by coaching and performance staff to develop position-specific training programs to optimize athlete preparation and facilitate on-field performance.

The present study provides a unique investigation of the perceived wellness associated with pre-season training camp in NCAA division I football players. Significant ($p<0.01$) differences were reported for every GPS and IA practice variable, except sprint distance, from the preceding day, distinguishing a perceived fatigue rating of 1 or 2 from a 3, and a 3 from a 4 or 5. These data indicate the movement characteristics of players on a day-to-day basis during training camp reflect individual perceptions of fatigue, and support the integration of perceived wellness measures for athlete load management during training to avoid decrements in performance and compromised player development. Results of the present study are consistent with previous work (27) using a similar questionnaire in Australian rules football, which reported an increased training load on the preceding day being associated with lower wellness scores the following day during pre-season training camp. A six-week intensified training period in Rugby League players resulted in significant ($p<0.05$) increases in perceived fatigue with simultaneous significant ($p<0.05$) decreases in sprint and agility performance, that was followed by significant ($p<0.05$) improvements in both perceived fatigue and performance measures following a two-week period of reduced training (64). Examinations (153, 230) of perceived fatigue following Rugby League competition reported significantly ($p<0.05$) less favorable fatigue scores accompanied by significant ($p<0.05$) reductions in neuromuscular performance, with perceptions of fatigue and soreness outlasting reductions in performance measures. In Australian footballers, Gallo et. al. (82), reported that pre-training ratings of perceived wellness significantly impacted PL during the subsequent practice session. Although the present study did not examine the impact of perceived fatigue on subsequent practice variables, unfavorable ratings of perceived fatigue may potentially alter exercise tolerance, thereby reducing the quality of practice on the same day. The results of the present study confirm those of previous investigations (27, 153, 230) highlighting the importance of quantifying and managing the external training load in addition to the perceived fatigue of NCAA division I football players, particularly during and immediately following pre-season training camp. Employing subjective wellness questionnaires similar to the one utilized in the present study, appears to be an effective means of monitoring the internal response to pre-season training camp practices in college football players. Members of the performance staff should work in a collaborative manner with the goal of increasing the physical fitness, supporting the improvement of tactical and technical requirements, and mitigating the risk of undesirable outcomes which may include increased injury risk associated with increased feelings of fatigue (145), illness, and poor performance during pre-season training camp in NCAA division I football players.

Significant ($p<0.001$) differences in total, low-, medium-, and high-intensity running and acceleration and deceleration distance at all intensities were demonstrated between individuals who rated their level of perceived soreness a 1 or 2 and those who rated it a 3, 4, or 5. Significant ($p<0.05$) differences in PL distinguished soreness ratings of 1 or 2 from a 3, and a 3 from a 4 or 5. Examinations in Australian footballers (27) have also demonstrated daily variations in external load associated with pre-season training camp have a significant ($p<0.001$) impact on wellness measures, including soreness, fatigue, sleep quality, stress levels and mood the following day. The present study examined the effect of practice loads on perceived wellness the following day, however, muscle soreness may persist for longer periods following fast velocity eccentric muscle contractions that are characteristic of participation in contact team sports like college football (180). Although biochemical markers of soreness were beyond the scope of this study, significant ($p<0.05$) elevations in creatine kinase have been demonstrated in division I college football players following 4 and 7 days of pre-season training camp (62), likely resulting from the blunt force trauma and eccentric muscle actions associated with collisions and stretch shortening cycle exercise inherit to participation in contact team sports (158). Soreness following intense team sport exercise may be expected, however, clear guidelines do not exist as to what alterations, if any, in training load should be made in response to differing levels of soreness (144). Collectively, the performance team should examine the practice loads of athletes who report persistent soreness to determine if the soreness is an intended consequence of properly programmed loads or an unexpected result of excessive loading, and take appropriate measures, including the modification of subsequent training sessions to reduce the likelihood of cumulative fatigue and performance decrements.

No significant ($p<0.05$) differences in GPS and IA variables were reported relating to perceived sleep quality, however significantly ($p<0.05$) less running distance and acceleration and deceleration distance at all intensities were demonstrated for individuals rating perceived sleep quantity a 4 or 5 vs. a 1, 2, or 3. Additionally, significant ($p<0.05$) differences in GPS variables, including PL, high-intensity acceleration and deceleration distance, and max-intensity acceleration distance were able to distinguish a rating of a 1 or 2 from a 3, and a 3 from a 4 or 5. The findings of the present study are consistent with those of Hausswirth et. al. (101) who reported reductions in sleep quantity associated with overreached athletes participating in intense training. In German Football League players, less favorable ratings of perceived sleep were associated with a significantly ($p=0.01$) higher subsequent risk of injury, indicating that a lack of sleep, or non-refreshing sleep, increases injury risk (145). It is reasonable to suggest the reductions in sleep quantity observed in the present study may be attributed to the increased practice loads and the fatigue or muscle soreness associated with those loads (101). Libert et. al. (147) reported decreases in sleep quantity associated with exposure to heat before and during sleep, and as such, it is plausible to suggest that other factors including ambient environmental temperature, which were not controlled for in the present study, may potentially impact sleep. The results of the present study emphasize the importance of individualized athlete monitoring strategies, including perceived measures of sleep quantity, by those seeking to maximize on-field performance and mitigate the deleterious effects of fatigue associated with intense training.

Individuals who responded more favorably, indicated by a rating of a 4 or 5 for the subscale of perceived stress, demonstrated significantly ($p<0.05$) less PL, total, low-, medium-, and high-intensity running distance and acceleration and deceleration distance at all intensities, in the preceding practice session than those who rated perceived stress a 3. However, significant ($p<0.05$) differences were not established between those who rated stress a 4 or 5 compared to those who rated stress a 1 or 2 for many movement variables, which may be explained by the limited classification of unfavorable ratings for this particular subscale, thus skewing responses toward the normal or more favorable direction. Previous work (27) in Australian footballers has reported that an increase in daily training load associated with a pre-season training camp negatively impacted perceived stress the following day. Similarly, Rugby League players demonstrated increased stress and decreased recovery during an intensified training period (44) supporting the utility of monitoring the individual stress response associated with participating in contact team sports. The findings of the present study and previous examinations in contact team sports (27, 44) support the utility of monitoring the individual stress response associated with participating. Previous research (209) has indicated the subscale of emotional stress may provide limited utility for monitoring athlete well-being, while non-training stress has been identified as potentially useful in monitoring acute changes in wellness. The present study did not differentiate between the potential sources of stress, but rather identified stress as a global gestalt measure. In division I college football players, both physical and psychological stress have been positively associated with injury occurrence (152, 182), and as such, the inclusion of the stress subscale as part of the daily monitoring of athlete wellness may be advantageous in decreasing the likelihood of maladaptation resulting from all sources of stress associated with participation in division I college football.

The results of the present study provide novel insight into the position-specific movement demands of NCAA division I pre-season training camp and provide sport and performance coaches with quantified information, which may be used to optimally prepare football players for this intense period of physical training. The present study demonstrated sizeable differences in the positional movement demands of division I football players participating in pre-season camp, highlighting the importance of position-specific training programs to adequately address the physical demands associated with this period of training. In addition, the present study is the first to report the perceived wellness in NCAA division I football players following pre-season training camp practices. Substantial differences in volumes and intensities of GPS and IA movement variables were reported in athletes who responded more or less favorably on perceived wellness subscales. The use of wellness questionnaires may provide sport coaches and performance managers an increased understanding of the training response associated with pre-season training camp practice loads, and provide increased certainty when programming and adjusting the individual training load prescription in pre-season training camp. The ease of administration and cost effectiveness associated with monitoring the athlete training response through subjective means allows football teams, at all levels, to implement these strategies throughout the competitive season without the need for a significant time or monetary investment.

### 5.5 Practical Applications

Data from the present study increase our understanding of the physical movement demands of pre-season training camp in division I college football players, and provide scope for the design of position-specific training strategies for coaches seeking to optimize training for the demands of pre-season practice. A better understanding of the demands of positional movement demands and perceived wellness associated with pre-season training camp in NCAA division I football players is required to improve the analysis of individual performance characteristics and implement a systematic approach to the development of position-specific training programs. The results of the present study indicate considerable positional differences exist with respect to movement demands and perceived wellness scores during pre-season training camp in NCAA division I football players. Performance coaches should administer position-specific training programs during the summer conditioning period that adequately prepare players for the physical demands of pre-season camp. Specifically, an appropriate volume of total, high-intensity, and sprint distance, in addition to acceleration and deceleration distance should be undertaken prior to pre-season training camp.

The present study also provided a novel analysis of the physiological and psychological response to exercise loads associated with practice on the preceding day. These data support the use of daily perceived measures of wellness to quantify the internal response to practice loads in division I football players participating in pre-season training camp. Subjective measures of perceived wellness, including fatigue, soreness, sleep quantity, and stress appear to be sensitive to differences in training load from the preceding practice day in NCAA division I football players, and may be used to monitor the adaptive response to pre-season training camp practices. It is up to coaches and performance staff to determine if unfavorable wellness scores are an intended consequence of participation in pre-season practices or an unintended result of improper practice volumes and intensities. Minimizing the deleterious effects of fatigue while simultaneously improving the position-specific technical, tactical, and physical demands associated with athlete preparation in division I college football players requires a collaborative effort between members of the coaching staff, medical staff, performance staff, and most importantly, the athletes themselves. The ease of administration, cost-effectiveness, and the minimal time investment required to collect perceived wellness data, makes it a practical tool for monitoring team sport athletes.

Data obtained from the present study provide a better understanding of the movement demands and the resultant physiological and psychological responses of NCAA division I football players to pre-season training camp. This information provides a foundation from which to implement a systematic approach to the development of individual and position-specific training programs that adequately prepare athletes for the rigors of this period of time. Future investigations should examine the impact of perceived wellness scores on performance and injury risk.

## Chapter 6

## A Comparison of Pre-Season and In-Season Practice and Game Loads in NCAA Division I Football Players

### 6.1 Introduction

American football is a full-contact team sport characterized by high-speed running and frequent accelerations, decelerations, change of direction specific impacts, and blunt force trauma resulting from repeated contact with opponents and the ground during blocking, tackling, and ball carrying (216, 235, 236). Recent studies (235, 236) have provided novel insight to the positional movement demands associated with NCAA division I football, including the quantification of sprint distances and high-intensity accelerations and decelerations, and the frequency and intensity of positional impacts and rapid changes of direction associated with competition. Global positioning system (GPS) derived positional movement demands of NCAA division I football players during competition (235) and pre-season training camp (56) have been reported, however data describing the daily physical demands of the in-season period in college football, remain unestablished.

Global positioning systems technology with integrated triaxial accelerometers (IA) have provided a means of quantifying the physical demands of training and competition in contact team sports (74, 160, 235). Improvements in technology and sampling methodologies have increased the accuracy of data recorded via portable GPS and IA for applied research purposes (115), and have provided a valid and reliable means of assessing activity profiles in team sports (45, 117). Additionally, IA have demonstrated reliability (24) as a means of measuring physical activity across multiple players in team sports, with strong inter-unit relationships (r=0.996-0.999) demonstrated during high-intensity contact team sport activity.

College football teams generally participate in an intensified pre-season training camp that typically consists of a maximum of 29 practice sessions performed over a period of approximately 4-5 weeks prior to the first competitive event of the season (176). Pre-season training camp traditionally involves programming loads that are developed to maximize positive physical adaptation and minimize maladaptation that may be associated with acute and cumulative fatigue, presenting logistical and player management challenges for coaches and performance staff. Despite an increased understanding of the positional movement demands associated with competition and pre-season training camp practices, the daily physical demands associated with practices during the in-season competitive period remain unknown. A more comprehensive understanding of the daily physical demands associated with the in-season competitive period will augment our understanding of the demands of NCAA football players and provide scope for improvements in the planning of pre-season training camp practices to adequately prepare players for the demands of the in-season period. The aim of the present study was to quantify the individual practice and game loads throughout an NCAA division I football season to determine if significant differences exist between the training loads associated with pre-season training camp and those undertaken during the in-season competitive period. We hypothesize that there will be significant differences in training loads associated with pre-season training camp when compared to the in-season competitive period in NCAA division I football players.

## 6.2 Methods

### 6.2.1 Experimental Approach to the Problem

To examine practice session training loads during the in-season and pre-season periods of an NCAA division I football season, portable IA data were collected from players during 22 pre-season training camp practices, 36 regular season practices, and 12 competitions, completed between August 7 and November 28. The individual IA datasets in the present study represented subjects from all offensive and defensive position groups as follows: (WR: n=5), (OL: n=4), (RB: n=4), (QB: n=2), (TE: n=3), (DL: n=4), (LB: n=4), (DB: n=5). To determine inter-week PL differentials, each practice and game completed was assessed as a single observation.

### 6.2.2 Subjects

Thirty-one NCAA division I Football Bowl Subdivision (FBS) football players (age 20.5 ± 1.1 years; age range 18.6 – 22.9; height 187.6 ± 6.2 cm; and mass 106.8 ± 18.6 kg) participated in the present study. All subjects were collegiate athletes whom had been selected to participate in the football program prior to the commencement of the study. All participants in the present study completed the teams' 8-week summer off-season physical development training program that included a full-body strength and power training program and specific skills and conditioning sessions designed to simulate the demands of NCAA division I college football practice. The present study comprises the statistical analysis of data collected as part of the day-to-day student athlete monitoring and testing procedures within the university's football program. Ethical approval was obtained from the university's Institutional Review Board and all subjects signed an institutionally approved informed consent document prior to participating in the study.

### 6.2.3 Procedures

### 6.2.4 Global Positioning System Units

Positional movement data were collected from 22 pre-season practice sessions, 36 in-season practice sessions and 12 games using commercially available microtechnology units (OptimEye S5; Catapult Innovations, Melbourne, Australia). The units included a triaxial accelerometer (IA) which operated at 100 Hz and assessed the frequency and magnitude of full-body acceleration ($m \cdot s^{-2}$) in three dimensions, namely, anterior-posterior, mediolateral, and vertical (143, 158). Prior to the commencement of each practice and game, GPS receivers were placed outside for 15 minutes to acquire a satellite signal, after which, receivers were placed in a custom designed pocket attached to the shoulder pads of the subjects. Shoulder pads were custom-fit for each individual, thereby minimizing movement of the pads during practices. The GPS and IA receivers used in the present study were positioned in the center of the upper back, slightly superior to the scapulae. Subjects were outfitted with the same GPS receiver for each practice and game. Following the completion of practices, GPS receivers were removed from the shoulder pads, and subsequently downloaded to a computer for analysis utilizing commercially available software (Catapult Sprint 5.1, Catapult Innovations, Melbourne, Australia). In the present study, training load was determined via combined tri-axial accelerometer data and represented as PlayerLoad$^{TM}$ (PL), which is a modified vector magnitude expressed as the square root of the sum of the squared instantaneous rates of change in acceleration in each of the three planes and divided by 100 (24). Previous research has documented a strong correlation between PL and total distance in Australian football ($r = 0.97$, 95% CI: 0.96 – 0.98) (81). Boyd and colleagues (24) have demonstrated the laboratory intra-unit (0.91-1.05 % coefficient of variation [CV]) and inter-unit (1.02-1.10 % CV) reliability of PL and determined its inter-unit reliability in Australian rules football matches (1.90% CV). Findings from other team sports including basketball, netball, and Australian football have demonstrated the ability of accelerometer derived PL to differentiate between competitive games, scrimmage games, practice drills, positional demands, and levels of competition (23, 35, 166). The GPS and IA units utilized in the present study have demonstrated the ability to accurately detect collisions associated with contact team-sport participation (73, 109). Collision events identified by microtechnology devices during Rugby League match-play demonstrated a strong positive correlation with video coded collision events ($r=0.96$), with no difference between the number of collisions identified by microtechnology and video coding, and were sensitive to detect 97.6% of collisions that occurred (109). Previous research by Gabbett et. al. (73) has also demonstrated the ability of the GPS and IA units utilized in the present study to accurately identify collision events against video-based coding of actual collision events ($r=0.96$, $p<0.01$).

### 6.2.5 Phases of Season

For data analysis, the season was divided into four distinctive phases, namely pre-season week 1 (pre-season1), pre-season week 2 (pre-season2), pre-season week 3 (pre-season3), and 12 in-season weeks. Each week was represented as seven calendar days, and the number of practice sessions included for each pre-season practice week included: 8 for pre-season1 (3 full pads, 3 shoulder pads and helmet, 2 helmets only), 8 for pre-season2 (6 full pads and 2 shoulder pads and helmets), and 6 for pre-season3 (6 full pads). Two practices occurred on three separate days, namely days 6, 8, and 13 of pre-season training camp. Each in-season week consisted of a Tuesday (Game -4), Wednesday (Game -3), and a Thursday (Game -2) practice session, in addition to a game each Saturday.

### 6.2.6 Statistical Analyses

The present study quantifies the relative PL differential in NCAA division I college football players between three phases of training camp, in-season games, and Game -4, Game -3, and Game -2 practice sessions. Data were set at the practice level, where an observation for each player's maximum player load (PLMax) session from each training camp phase, or the mean player load (PLMean) across each training camp phase, was referenced against each player's respective PL resulting from each game, and Game -4, Game -3, or Game -2 practice session, for each week throughout the season. Additionally, a model was run examining the cumulative PL for each week from pre-season1 through the end of the competitive season. Nine OLS regressions, utilizing a control for each individual player, were used to determine the roster-level variation for in-season practices and games compared to each phase of training camp. Each model examined the in-season PL from a Game -4, Game -3, Game -2, or Game session against either the maximum player load achieved in each of the three phases of training camp, or the average player load across all sessions from each phase of training camp. Standard errors were clustered at the individual level due to the nested structure of the data throughout the season. Following completion of the regressions, post-hoc t-tests and pair-wise comparisons were used to establish inter-week significance for PL variation. Adjusted means for each training camp phase and in-season week are reported for each model in tables 1 and 2. Alpha intervals for all hypothesis testing were set at $p<0.05$ as the level of significance for statistical tests. All statistical analyses were performed using Stata Statistical/Data Analysis Software (Stata 14 for Windows, version 14.1; StataCorp, College Station, TX, USA).

The inclusion criteria for the Game -4, Game -3, and Game -2 models was full participation in a session, thus all observations where a player participated fully were used. In the case of unit malfunctions where an individual participated fully, player load was imputed for individuals based on their unique average for that type of session, which occurred on seven instances throughout the study. The inclusion criteria for the game day model was participation in ≥75% of the offensive or defensive plays, while the inclusion criteria for the cumulative PL model was full participation in all sessions in that given week. Thirty-one players were eligible for the present study.

### 6.3 Results

Several significant differences in PLMax (Table 21) and PLMean (Table 22) between pre-season training camp practices and in-season practice sessions were reported. Maximum and Mean PL were significantly ($p<0.05$) lower in pre-season2 and pre-season3 compared to pre-season1. Every in-season Game -4 practice session resulted in significantly ($p<0.05$) lower PL than the PLMax achieved in pre-season1. Additionally, Game -4 practice sessions in weeks 1-3 and 9-12 demonstrated significantly ($p<0.05$) lower PL than the PLMax reported in pre-season2 and pre-season3. Game -3 and Game -2 practices from every in-season week, except in-season week 5, resulted in significantly ($p<0.05$) lower PL than the PLMax demonstrated in pre-season1, 2, and 3. Five games exhibited significantly ($p<0.05$) lower PL than the PLMax reported in pre-season1, one game resulted in significantly ($p<0.05$) higher PL than the PLMax in pre-season1, while the remaining six games demonstrated no significant ($p<0.05$) differences than the PLMax in pre-season1.

An examination of PLMean resulting from pre-season training camp demonstrated significantly ($p<0.05$) greater PLMean in pre-season1 than all in-season Game -3 and Game -2 practice sessions, and 9 out of 12 Game -4 practice sessions. The in-season week 1 Game -4 practice session PL was significantly ($p<0.05$) lower than the PLMean in pre-season1, 2 and 3, while Game -4 practice sessions in weeks 2-8 demonstrated significantly ($p<0.05$) higher PL than the PLMean reported in pre-season2 and 3. No significant ($p<0.05$)

differences were established between Game -4 practice sessions in weeks 9-12 and those demonstrated in pre-season2 and 3. Four in-season Game -3 practices resulted in significantly ($p<0.05$) higher PL than PLMean in pre-season2, while another four Game -3 practices resulted in significantly ($p<0.05$) lower PL than the PLMean in pre-season2. All Game -2 practice sessions were associated with significantly ($p<0.05$) lower PL than the PLMean reported for pre-season2 and 3. Ten out of twelve games resulted in significantly ($p<0.05$) higher PL than the PLMean demonstrated in pre-season1, while all games were associated with significantly ($p<0.05$) higher PL than the PLMean achieved in pre-season2 and 3.

The cumulative PL (Table 22) resulting from pre-season1 was significantly ($p<0.05$) greater than that of pre-season2 and 3, and the cumulative PL in pre-season2 was significantly greater than that of pre-season3. All pre-season weeks demonstrated significantly ($p<0.05$) higher cumulative PL than the cumulative PL resulting from all 12 in-season weeks.

**Table 21.** PLMax Predicted Means. [1] Significantly different than Pre-1, [2] Significantly different than Pre-2, [3] Significantly different than Pre-3.
Line 2: Lower and Upper limits of 95% Confidence Interval

| Seasonal Week | Game -4 | Game -3 | Game -2 | Game |
|---|---|---|---|---|
| Pre-Season1 | **579.9**<br>(554.5, 605.3) | **578.8**<br>(554.3, 603.2) | **581.3**<br>(555.5, 607.1) | **564.3**<br>(539.1, 589.6) |
| Pre-Season2 | **460.8**[1]<br>(440.4, 481.2) | **461.0**[1]<br>(442.2, 479.7) | **464.7**[1]<br>(442.5, 486.8) | **446.7**[1]<br>(425.8, 467.5) |
| Pre-Season3 | **442.9**[1]<br>(427.6, 458.1) | **441.7**[1]<br>(426.2, 457.2) | **444.2**[1]<br>(423.7, 464.6) | **427.2**[1]<br>(404.7, 449.8) |
| In-Season 1 | **353.3**[123]<br>(336.2, 370.4) | **322.0**[123]<br>(306.3, 337.7) | **285.5**[123]<br>(274.2, 296.8) | **538.1**[23]<br>(493.8, 582.4) |
| In-Season 2 | **406.9**[123]<br>(392.4, 421.3) | **420.4**[123]<br>(405.1, 435.8) | **328.2**[123]<br>(312.0, 344.3) | **567.2**[23]<br>(543.8, 590.7) |
| In-Season 3 | **415.8**[123]<br>(397.6, 433.9) | **395.6**[123]<br>(380.0, 411.2) | **270.0**[123]<br>(245.1, 294.9) | **605.7**[123]<br>(584.0, 627.5) |
| In-Season 4 | **451.3**[1]<br>(436.1, 466.5) | **408.9**[123]<br>(393.4, 424.4) | **307.0**[123]<br>(293.2, 320.7) | **525.5**[123]<br>(498.4, 552.7) |
| In-Season 5 | **477.3**[13]<br>(456.5, 498.2) | **425.6**[12]<br>(407.8, 443.5) | **325.4**[123]<br>(309.0, 341.7) | **527.4**[123]<br>(508.2, 546.6) |
| In-Season 6 | **437.7**[1]<br>(420.0, 455.5) | **408.9**[123]<br>(393.8, 423.9) | **298.6**[123]<br>(286.6, 310.5) | **514.5**[123]<br>(483.2, 545.8) |
| In-Season 7 | **467.1**[1]<br>(440.7, 493.6) | **410.8**[123]<br>(388.5, 433.1) | **308.7**[123]<br>(293.2, 324.1) | **599.3**[23]<br>(567.4, 631.3) |
| In-Season 8 | **424.8**[12]<br>(410.7, 438.9) | **412.5**[123]<br>(397.5, 427.5) | **325.6**[123]<br>(313.0, 338.3) | **447.3**[1]<br>(432.5, 462.0) |
| In-Season 9 | **394.7**[123]<br>(380.8, 408.7) | **391.9**[123]<br>(379.3, 404.6) | **266.5**[123]<br>(254.2, 278.8) | **557.2**[23]<br>(539.2, 575.2) |
| In-Season 10 | **401.3**[123]<br>(381.1, 421.5) | **353.9**[123]<br>(331.8, 376.0) | **315.9**[123]<br>(295.3, 336.4) | **488.3**[13]<br>(455.6, 520.9) |
| In-Season 11 | **381.0**[123]<br>(352.4, 409.6) | **347.6**[123]<br>(326.4, 368.7) | **332.5**[123]<br>(301.5, 363.5) | **530.8**[23]<br>(508.9, 552.7) |
| In-Season 12 | **386.0**[123]<br>(370.1, 401.9) | **357.8**[123]<br>(344.7, 371.0) | **317.6**[123]<br>(302.0, 333.1) | **549.0**[23]<br>(529.7, 568.2) |
| # of Observations | 422 | 422 | 423 | *252 |

*Includes only observations in which there was full participation in Game -4, Game -3, and Game -2 practice sessions and ≥ 75% game participation.

**Table 22.** PLMean and Cumulative PL Predicted Means. [1] Significantly different than Pre-1, [2] Significantly different than Pre-2, [3] Significantly different than Pre-3.
Line 2: Lower and Upper limits of 95% Confidence Interval

| Seasonal Week | Game -4 | Game -3 | Game -2 | Game | Cumulative Weekly Player Load |
|---|---|---|---|---|---|
| Pre-Season1 | **466.8**<br>(449.7, 484.0) | **465.7**<br>(450.6, 480.8) | **468.2**<br>(450.6, 485.8) | **453.2**<br>(437.1, 469.4) | **3757.5**<br>(3611.5, 3903.4) |
| Pre-Season2 | **385.7** [1]<br>(366.9, 404.5) | **385.9** [1]<br>(368.9, 403.0) | **389.6** [1]<br>(371.2, 408.0) | **373.5** [1]<br>(354.9, 392.0) | **3563.9** [1]<br>(3423.4, 3704.3) |
| Pre-Season3 | **377.1** [1]<br>(363.4, 390.8) | **375.9** [1]<br>(363.8, 388.1) | **378.4** [1]<br>(363.4, 393.4) | **363.5** [1]<br>(342.0, 384.9) | **1937.7** [12]<br>(1861.8, 2013.6) |
| In-Season 1 | **353.8** [123]<br>(337.2, 370.4) | **322.5** [123]<br>(307.3, 337.7) | **286.0** [123]<br>(275.8, 296.1) | **537.6** [123]<br>(493.9, 581.4) | **1412.9** [123]<br>(1352.9, 1473.0) |
| In-Season 2 | **406.8** [123]<br>(392.6, 420.9) | **420.3** [123]<br>(404.9, 435.6) | **328.0** [123]<br>(311.4, 344.6) | **566.5** [123]<br>(541.2, 591.8) | **1572.8** [123]<br>(1514.5, 1631.2) |
| In-Season 3 | **415.7** [123]<br>(397.2, 434.4) | **395.6** [1]<br>(379.8, 411.5) | **270.0** [123]<br>(245.1, 294.9) | **606.5** [123]<br>(583.7, 629.3) | **1518.2** [123]<br>(1451.3, 1585.1) |
| In-Season 4 | **451.7** [23]<br>(436.2, 467.2) | **409.3** [123]<br>(393.9, 424.7) | **307.4** [123]<br>(293.9, 320.8) | **524.4** [123]<br>(498.0, 550.8) | **1642.0** [123]<br>(1576.5, 1707.4) |
| In-Season 5 | **477.7** [23]<br>(456.8, 498.6) | **426.0** [123]<br>(407.9, 444.1) | **325.8** [123]<br>(309.4, 342.2) | **526.5** [123]<br>(508.0, 545.1) | **1626.1** [123]<br>(1570.4, 1681.8) |
| In-Season 6 | **437.8** [123]<br>(420.0, 455.6) | **409.0** [13]<br>(393.6, 424.4) | **298.7** [123]<br>(286.8, 310.5) | **515.7** [123]<br>(483.8, 547.5) | **1522.1** [123]<br>(1477.1, 1567.1) |
| In-Season 7 | **467.2** [23]<br>(440.4, 493.9) | **410.8** [13]<br>(388.4, 433.2) | **308.7** [123]<br>(293.1, 324.3) | **599.6** [123]<br>(567.4, 631.8) | **1645.2** [123]<br>(1581.1, 1709.3) |
| In-Season 8 | **424.9** [123]<br>(410.4, 439.3) | **412.5** [123]<br>(397.7, 427.4) | **325.7** [123]<br>(313.2, 338.2) | **446.7** [23]<br>(433.4, 459.9) | **1532.3** [123]<br>(1489.4, 1575.3) |
| In-Season 9 | **394.8** [1]<br>(381.2, 408.3) | **392.0** [1]<br>(379.4, 404.6) | **266.5** [123]<br>(254.6, 278.4) | **555.7** [123]<br>(537.1, 574.3) | **1467.0** [123]<br>(1430.0, 1503.9) |
| In-Season 10 | **401.0** [1]<br>(380.9, 421.1) | **353.7** [12]<br>(332.1, 375.2) | **315.6** [123]<br>(295.9, 335.3) | **486.6** [23]<br>(454.7, 518.5) | **1435.8** [123]<br>(1377.0, 1494.6) |
| In-Season 11 | **381.1** [1]<br>(352.5, 409.7) | **347.6** [12]<br>(325.9, 369.3) | **332.6** [123]<br>(301.7, 363.5) | **528.2** [123]<br>(507.2, 549.1) | **1446.0** [123]<br>(1362.8, 1529.1) |
| In-Season 12 | **385.6** [1]<br>(369.7, 401.6) | **357.5** [12]<br>(344.6, 370.4) | **317.2** [123]<br>(302.0, 332.4) | **547.2** [123]<br>(526.4, 568.1) | **1472.5** [123]<br>(1410.9, 1534.0) |
| # of Observations | 422 | 422 | 423 | *252 | 415 |

*Includes only observations in which there was full participation in Game -4, Game -3, and Game -2 practice sessions and ≥ 75% game participation.

The average and maximum session duration for pre-season1, pre-season2, pre-season3, Game -4, Game -3, and Game -2 practice sessions, in addition to average and maximum game durations, are described in Table 23.

**Table 23.** Average and Maximum Practice Session Durations

| Seasonal Week | # of Sessions | Average Duration | Maximum Duration |
|---|---|---|---|
| Pre-Season1 | 8 | 2:25:42 | 2:49:05 |
| Pre-Season2 | 8 | 2:03:20 | 2:20:00 |
| Pre-Season3 | 6 | 1:55:00 | 2:05:00 |
| In-season Game -4 | 12 | 1:58:19 | 2:05:00 |
| In-Season Game -3 | 12 | 1:52:49 | 2:04:33 |
| In-Season Game -2 | 12 | 1:32:06 | 1:36:00 |
| Game | 12 | 3:19:17 | 3:40:00 |

## 6.4 Discussion

The aim of the present study was to quantify the individual practice and game loads throughout an NCAA division I football season to determine if significant differences exist between the training loads associated with pre-season training camp and those undertaken during the in-season competitive period. The results of the present study contribute novel insight into the practice and competitive loads experienced by NCAA division I college football players throughout the pre-season and in-season periods, and provide scope for the programming of pre-season practices and the design of physical conditioning strategies to prepare athletes for the rigors of pre-season training camp.  The results confirm our hypothesis that significant differences in training loads associated with pre-season training camp, when compared to the in-season competitive period in NCAA division I football players, exist. The most notable findings were the significantly ($p<0.05$) greater PLMax values attributed to pre-season1 compared to PL resulting from all in-season practices, and the significantly ($p<0.05$) higher cumulative PL reported for pre-season1, 2, and 3 compared to the cumulative PL for every in-season week.

In the present study, pre-season1 resulted in significantly (P<0.05) higher PLMax and PLMean values than both pre-season2 and pre-season3.  The PLMax achieved in the first week of pre-season camp was significantly (p<0.05) higher than the PL resulting from 42% of games, and all Game -4, Game -3, and Game -2 practice sessions throughout the in-season period.  The PLMean resulting from pre-season1 was significantly (p<0.05) higher than PL values of all Game -3 and Game -2 practices, nine of twelve Game -4 practice sessions, and two games.  These data clearly demonstrate that pre-season1 exposed players to the highest PL of the pre-season and in-season practice period, in addition to significantly (p<0.05) higher PL than 5 out of 12 games.  Indeed, only one game was associated with a significantly (p<0.05) higher PL than the PLMax achieved in pre-season1.   Collectively, these data contrast training load progression recommendations provided to mitigate injury risk (110) and optimize athlete preparation prior to the commencement of the NCAA division I football season.

It is widely understood that the appropriate planning of single and multi-day pre- and in-season training sessions is a fundamental aspect of optimal performance, however limited data exits to support a specific approach to programming training sessions in team sports (170).  Comparing the results of the present study with previous examinations is problematic due to the lack of similar investigations in NCAA division I football.  Previous investigations in Australian football have reported increased training loads and training session duration in the pre-season period when compared to the in-season competitive period (170, 195).  While similarities may exist between Australian football and NCAA division I college football, direct comparisons between the pre-season periods in each of these sports is problematic, most notably due to the duration of the pre-season period in Australian football, often lasting more than 20 weeks (170), while college football pre-season practice takes place over approximately four weeks.  In NCAA division I college football, GPS-derived positional movement characteristics have been quantified (235), and biochemical markers of muscle damage associated with pre-season training camp have been examined (62, 104).  However, research has not attempted to quantify the differences that may exist between practice loads encountered by NCAA division I football players during pre-season training camp with those experienced during the in-season period, and previously this information was limited to coaching intuition and anecdotal reports. It is clear that pre-season training camp is a critical period for football players, yet recommendations have not been established which elucidate effective strategies for periodizing pre-season training camp practices to maximize the position-specific tactical, technical, and physical demands while minimizing the deleterious effects of fatigue. Periodization refers to the logical and systematic process of sequencing and integrating training interventions to achieve peak performance at the appropriate times (95). An ideology that highlights the influence of a properly periodized period of training is referred to as the stimulus-fatigue-recovery-adaptation theory, which suggests that the greater the overall magnitude of the physical demands, the more fatigue accumulates, and the longer the recovery and adaptation process takes (95). When comparing in-season to pre-season practice demands, it is reasonable to suggest that the fatigue associated with pre-season training camp practices in the present study may require increased time recover from, and adapt to, the imposed demands.

In the present study, an in-season week of training consisted of three practices and one game, while pre-season1 was comprised of eight practice sessions in the first seven days, and as such, the cumulative training load resulting from pre-season1 is increased compared to a typical in-season week of training. This however, does not explain the significantly ($p<0.05$) greater PLMean and PLMax reported for individual practice sessions of pre-season1, which was likely the result of not only the composition, but the duration of the practice sessions. A greater portion of practice time in pre-season1 was devoted to position-specific skills and techniques than on situational and tactical planning in an offensive or defensive group setting, which commonly occurs throughout in-season practice sessions when preparing for competition. Individual skill work takes place in smaller groups, and allows for increased frequency of movement, potentially resulting in higher PL. The mean session duration in pre-season1 was 145 minutes, however the first practice session of pre-season1 was 169 minutes in duration, which represented the longest practice session of the entire season. The significant increases in PLMax and PLMean that occurred during pre-season1 may therefore, be also attributed to practice session duration. Previous research (195) in Australian football has demonstrated reductions in session duration accompany similar reductions in PL. Specifically, a 30% reduction in duration resulted in a ~30%

reduction in PL, and as such, periodizing practice duration may be an effective strategy to reduce PL and facilitate between session recovery to reduce injury risk and optimize subsequent practice session performance.

The PLMax and PLMean values reported in pre-season2 were not significantly different than pre-season3, however a significant ($p<0.05$) decrease in both PL measures was demonstrated compared to pre-season1. Week 2 of pre-season consisted of eight practice sessions with an average practice session duration of 123 minutes. Practice sessions in pre-season2 were programmed to provide less time dedicated to individual position-specific skill work and a larger amount of time to periods of situational drills involving the entire offensive and defensive teams. During the in-season period, the Game -4 practice sessions were planned as the highest practice loads of the week, and PL resulting from in-season Game -4 practices were significantly ($p<0.05$) greater than PLMean in pre-season2 for weeks 2 – 8 during the in-season period. The PL associated with the Game -4 practice session for in-season week 1 was significantly ($p<0.05$) lower than the PLMean in pre-season2, the likely result of a reduction in session duration in attempt to mitigate any deleterious effects of fatigue accumulated in pre-season training camp. A similar pattern was demonstrated for Game -3 practice sessions whereby in-season week 1, 10, 11, and 12 demonstrated significantly ($p<0.05$) lower PL than the PLMean reported in pre-season2. These findings illustrate that coaches may intuitively reduce practice loads during in-season, particularly in the latter part, to maintain the physical capacities developed throughout the pre-season and early in-season periods, but to also provide adequate recovery to support optimal gameday performance.

A comparison of PLMean from pre-season3 practice sessions with PL resulting from in-season Game -4 and Game -3 practice sessions reveals a decrease in training loads for weeks 9-12 of the season. This appears to be the result of a pre-planned reduction in session duration for Game -4 and Game -3 practices the last four weeks of the season. Similar reductions in PL associated with Game -2 practices sessions for the last 4 weeks of the season were not demonstrated, most likely due to the consistent nature of load programming for Game -2 practice sessions.

An examination of the cumulative weekly PL revealed significantly ($p<0.05$) greater cumulative PL for pre-season1 than pre-season2 and 3, and significantly ($p<0.05$) greater cumulative PL for pre-season2 than pre-season3. Additionally, all pre-season weeks were associated with significantly ($p<0.05$) greater cumulative PL than all in-season weeks. The significantly ($p<0.05$) increased cumulative workloads demonstrated in pre-season training camp most likely resulted from the increased number of practices when compared to a typical in-season week. However, along with the increased session frequency associated with pre-season training camp, the workloads, particularly in pre-season1, were also significantly ($p<0.05$) greater than Game -4, Game -3, and Game -2 in-season practice sessions. Additionally, only one game demonstrated a significantly ($p<0.05$) higher PL than the PLMax achieved in pre-season1. While the PLMax achieved in pre-season1 is comparable to the PL which may be experienced by NCAA division I football players during competition, it is reasonable to question the appropriateness of this particular loading scheme for week one of pre-season training camp, particularly in light of previous research demonstrating increased risk of injury and illness associated with acute spikes in training load indicative of pre-season training camp (110, 184).

American football is associated with high levels of physicality, and as such, practice sessions require adequate intensity to prepare for competitive demands. To improve the likelihood for success, coaches regularly plan practice sessions, which challenge the barriers of what players can achieve without exceeding individual training tolerance capacity (184). The present study demonstrated significantly ($p<0.05$) higher workloads in pre-season1 than any other phase of pre-season camp, and although the optimal pre-season practice session training load required to produce favorable physical adaptations and mitigate undesirable consequences associated with excessive fatigue has not been established, improvements in load programming may prove advantageous. Research in similar collision-based team sport (110) has demonstrated unfavorable outcomes associated with acute increases in training loads commonly seen in the first week of pre-season practice in NCAA division I football players. An examination (110) of the ratio of acute workload, represented as total distance accumulated over seven days, compared to chronic workloads, calculated as the 4-week rolling average acute workload, was found to be predictive of injury in Rugby League. Specifically, when players were subjected to an acute 7-day workload that was classified as ~ twofold greater than the workload in which they were accustomed to, up to a 10-fold increase in injury occurred. Piggott et. al (184) demonstrated acute spikes in weekly training load (>10%) accounted for ~40% of illness and injury in the subsequent 7-day period in Australian footballers. Colby et. al. (39) reported 3-weekly workloads to have the strongest relationship with intrinsic injury incidence in the pre-season and in-season period. Large week-to-week changes in training load also increased the risk of injury in professional rugby players (48). However, increased participation in pre-season practices may reduce the likelihood of injury during the in-season period, presumably by allowing players to accumulate high chronic workloads (110), and perhaps by identifying players who are able to handle higher pre-season training loads and therefore are more robust to injury (239). Performance coaches must have a clear understanding of the planned practice loads associated with pre-season training camp, particularly within the first week, and tailor the preceding weekly conditioning loads leading up to training camp, accordingly. A collaborative approach to pre-season training camp should be implemented, whereby the coaching staff, performance staff, and the medical staff work jointly to develop appropriate loading protocols prior to, and during pre-season training camp, which serve to improve the sport-specific physical capacities but avoid the abrupt increases in PL which have been associated with injury and illness.

The results of the present study provide novel insight into the contrasting physical demands of NCAA division I football players between the pre-season, particularly in pre-season1, and in-season periods. The findings of the study may seem intuitive to those intimately involved in NCAA division I football, however this is the first investigation to elucidate these suspicions objectively. Despite the novel findings, these data represent one team competing in NCAA division I college football, and consequently, the findings may be limited to this specific team and the philosophy of this particular coaching staff.

### 6.5 Practical Applications

The results confirm our hypothesis that significant differences in training loads associated with pre-season training camp, when compared to the in-season competitive period in NCAA division I football players, exist. The most notable findings were the significantly ($p<0.05$) greater PLMax values attributed to pre-season1 compared to PL resulting from all in-season practices, and the significantly ($p<0.05$) higher cumulative PL reported for pre-season1, 2, and 3 compared to every in-season week.  Data from the present study augment our understanding of the practice demands experienced by NCAA division I college football players, and provide scope for the improvement of pre-season practice design and physical conditioning strategies for coaches seeking to optimize performance.

The commencement of the competitive season in college football is highly anticipated by players and coaches alike, and as such, may result in excessive programming of practice volumes and intensities, particularly in pre-season1.  An examination (78) in Rugby League demonstrated that reductions in pre-season training load, via decreases in session duration, resulted in decreased rates of injury, without negatively impacting improvements in physical fitness.  Similar investigations in NCAA football have not been undertaken, however a more deliberate increase in training load, resulting from calculated increases in session duration may be warranted.  Purposeful planning of pre-season training camp practices requires collaboration between the sport coaches, performance staff, and medical staff.  Limiting the practice session duration, particularly for the initial practices, and throughout first week of pre-season, may prove to be worthwhile.

For many NCAA football teams, the first week of pre-season camp represents an acute, and often times, significant increase in training load.  Coaches seeking to maximize performance and minimize the negative effects of fatigue should make efforts to lessen these acute increases by tightly controlling factors contributing to increases in training load in pre-season1, and by ensuring athletes are accustomed to these loads prior to the start of pre-season camp.  This may be accomplished by limiting the duration of the first pre-season training camp practice, followed by gradual increases in session duration throughout pre-season1. Additionally, performance coaches should program physical conditioning loads in the weeks leading up to pre-season training camp, that approximate the physical movement demands of pre-season practice sessions. Collectively, these measures may assist in ensuring that the first week of pre-season training camp represents a ≤10% increase in training load, and may reduce the likelihood of maladaptation associated with excessive fatigue and under-recovery.

Future studies should examine how coaches seeking to enhance performance, can manipulate pre-season practice loads, at the team, position, and individual level, to mitigate fatigue, enhance recovery, and optimize game-day performance.

# Chapter 7

# Perceived Wellness Associated With Practice and Competition in NCAA Division I Football Players

## 7.1 Introduction

American football is a full-contact team sport associated with intense physical demands, characterized by frequent collisions and blunt force trauma associated with repeated contact with opponents and the ground during blocking, tackling, and ball-carrying activities, in addition to high-speed running and frequent accelerations, decelerations, and change of direction specific impacts (216, 235, 236). Global positioning systems (GPS) technology with integrated triaxial accelerometers (IA) have provided a means of quantifying the physical demands of training and competition in NCAA division I football (235, 236) and similar contact team sport (74, 160). Recent studies (235, 236) have provided novel insight into the positional movement demands associated with NCAA division I football, including the quantification of sprint distances and high-intensity accelerations and decelerations, and the frequency and intensity of positional impacts and rapid changes of direction associated with competition.

The intense nature of competition in NCAA division I football necessitates the prudent programming of in-season practice loads that maintain position-specific physical demands and minimize excessive fatigue that may be associated with maladaptation and underperformance. Consequently, the judicious monitoring of the individual physiological and psychological response, commonly referred to as internal load, to exercise loads encountered in practice and competition is vital for maximizing competitive performance (20, 97). Investigations in contact team sport, including American football, have examined potential measures of an athlete’s internal load, including subjective or perceived wellness, and biochemical and neuromuscular responses to training and competition (72, 153, 230), however ambiguity exists as to which methods are most pertinent (97).

Perceived measures of wellness are efficient, inexpensive and non-invasive to the athlete (150). Additionally, wellness measures have demonstrated sensitivity to training stress, exhibiting a dose-response relationship with exercise load (209), and may be more efficacious than objective measures in identifying internal load (209). While subjective measures have demonstrated accuracy in assessing athletes' internal response to training and competition loads, the comprehensive nature of some forms presents substantial logistical challenges in many applied settings (228). A survey of the current trends in fatigue monitoring among high-performance sport revealed 84% of the respondents used subjective questionnaires, 80% of which utilized custom designed forms consisting of 4-12 items (225). Based upon current practices and previous recommendations for athlete monitoring (106), the implementation of brief, customized questionnaires to quantify the internal response of individuals participating in team-sports is supported.

Previous research (72, 235) has provided an increased understanding of the positional movement demands and the time-course of perceived recovery resulting from practice and competition NCAA division I football players. Currently, the impact of GPS-derived movement variables associated with practice and game demands on perceived wellness during the in-season competitive period remain ambiguous. A more comprehensive understanding of the perceived psychological response to the movement demands of practice and competition will provide performance staff a model from which to plan post-game recovery modalities and program subsequent training sessions. Further, evaluating the impact of weekly in-season practice loads on perceived wellness will provide novel insight for coaches seeking to manage the deleterious effects of fatigue and optimize subsequent game-day performance.

The aims of the present study were to (a) assess post-game (Game +1) recovery to determine which GPS-derived game day variables influence post-game perceived wellness in NCAA division I football players (b) to determine which GPS-derived movement variables accumulated during in-season weekly practice sessions influence perceived wellness two days prior to NCAA division I football games (Game -2). We hypothesized that there will be significant differences in GPS-derived movement variables in NCAA division I football players who reported differential ratings of perceived wellness on both Game +1 and Game -2.

## 7.2 Methods

### 7.2.1 Experimental Approach to the Problem

Two statistical models were utilized to accomplish the aims of the present study. A 'Game +1' model examined GPS and IA derived workloads resulting from Saturday games and the subsequent perceived wellness on the following day. The 'Game -2 model' examined the impact of GPS and IA derived workloads accumulated Game -4 and Game -3, on Game -2 perceived wellness. Researchers examined GPS and IA technology data collected from players during 24 regular season practices and 12 competitions completed throughout the in-season period of an NCAA division I football season. Data in the present study were grouped at the individual level and included the following positional observations: Wide Receiver (WR): 94 (52 Game +1, 42 Game -2), Offensive Linemen (OL): 98 (51 Game +1, 47 Game -2), Running Back (RB): 70 (36 Game +1, 34 Game -2), Quarterback (QB): 24 (12 Game +1, 12 Game -2), Tight End (TE): 69 (36 Game +1, 33 Game -2), Defensive Tackle (DT): 48 (26 Game +1, 22 Game -2), Defensive End (DE): 50 (26 Game +1, 24 Game -2), Linebacker (LB): 85 (39 Game +1, 46 Game -2), and Defensive Back (DB):112 (54 Game +1, 58 Game -2).

To assess perceived wellness associated with in-season practice and competition, a modified wellness questionnaire (Figure 1) was completed by participants every day following a game (Game +1), as well as in the morning prior to any physical activity on Game -2. A total of 656 observations (332 Game +1 and 324 Game -2) were included in the present examination. For the purposes of examining perceived wellness associated with games, only GPS and IA data where a survey was completed the following day were included in the analysis. To determine the impact of in-season weekly practice sessions on subjective markers of perceived wellness on Game -2, only movement data where an individual completed a survey on Game -2 and participated in Tuesday (Game -4) and Wednesday (Game -3) practice sessions, were included for analysis.

### 7.2.2. Subjects

Thirty NCAA division I Football Bowl Subdivision (FBS) football players (age 20.5 ± 1.1 years; age range 18.6 – 22.9; height 187.8 ± 6.2 cm; and mass 107.4 ± 18.6 kg) participated in the present study. All subjects were collegiate athletes whom had been selected to participate in the football program prior to the commencement of the study. All participants in the present study completed an 8-week summer off-season physical development training program that included a full-body strength and power training program and specific skills and conditioning sessions designed to simulate the demands of NCAA division I college football practice. The present study comprises the statistical analysis of data collected as part of the day-to-day student athlete monitoring and testing procedures within the university's football program. Ethical approval was obtained from the university's Institutional Review Board and all subjects signed an institutionally approved informed consent document prior to participating in the study.

### 7.2.3 Procedures

### 7.2.4 Global Positioning System Units

Positional movement data were collected from 24 in-season practice sessions and 12 games using commercially available microtechnology units (OptimEye S5; Catapult Innovations, Melbourne, Australia) operating at a frequency of 10 Hz . The units included a triaxial accelerometer (IA) which operated at 100 Hz and assessed the frequency and magnitude of full-body acceleration ($m \cdot s^{-2}$) in three dimensions, namely, anterior-posterior, mediolateral, and vertical (143, 158). Prior to the commencement of each practice and game, GPS receivers were placed outside for 15 minutes to acquire a satellite signal, after which, receivers were placed in a custom designed pocket attached to the shoulder pads of the subjects. Shoulder pads were custom-fit for each individual, thereby minimizing movement of the pads during practice and competition. The GPS and IA receivers used in the present study were positioned in the center of the upper back, slightly superior to the scapulae.

Subjects were outfitted with the same GPS receiver for each practice and game. Following the completion of practices and games, GPS receivers were removed from the shoulder pads, and subsequently downloaded to a computer for analysis utilizing commercially available software (Catapult Sprint 5.1, Catapult Innovations, Melbourne, Australia). Combined tri-axial accelerometer data were represented as PlayerLoad™ (PL), which is a modified vector magnitude expressed as the square root of the sum of the squared instantaneous rates of change in acceleration in each of the three planes and divided by 100 (24). Boyd and colleagues (24) have demonstrated the laboratory intra-unit (0.91-1.05 % coefficient of variation [CV]) and inter-unit (1.02-1.10 % CV) reliability of PL and determined its inter-unit reliability in Australian rules football matches (1.90% CV). Findings from other team sports including basketball, netball, and Australian football have demonstrated the ability of accelerometer derived PL to differentiate between competitive games, scrimmage games, practice drills, positional demands, and levels of competition (23, 35, 166). Improvements in technology and sampling methodologies have increased the accuracy of data recorded via portable GPS for applied research purposes (115), and have provided a valid and reliable means of assessing activity profiles in team sports (45). Previous research (45) has demonstrated the validity of GPS, with GPS-derived distance measures within 5% of a criterion distance, and intra-unit reliability of distance measures, within 4.5 m (90% CI: 3.5-6.6 m) (45). Additionally, IA have demonstrated reliability (24) as a means of measuring physical activity across multiple players in team sports, with strong inter-unit relationships ($r$=0.996-0.999) demonstrated during high-intensity contact team sport activity.

### 7.2.5 Movement Classification System

Movement profile classifications have been described for game analysis in American football (235) and similar contact team sports (156). The classification profile utilized in the present study was selected by the researchers to more accurately reflect the demands of American football (235). Each movement classification was coded as one of four speeds of locomotion. Low-intensity movements, such as standing, walking and jogging, were considered to be 0 – 12.9 $km \cdot h^{-1}$, medium-intensity movements, such as striding and running, were considered to be 13.0 – 19.3 $km \cdot h^{-1}$, high-intensity movements, such as fast running for some positional groups, and sprinting for others, were classified as 19.4 – 25.8 $km \cdot h^{-1}$, and sprinting movements were classified as exceeding 25.8 $km \cdot h^{-1}$. Short duration high-intensity movements, or measures of acceleration and deceleration, were classified as four groups, specifically low-intensity (0 – 1.0 $m \cdot s^{-2}$), medium-intensity (1.1 – 2.0 $m \cdot s^{-2}$), high-intensity (2.1 – 3.0 $m \cdot s^{-2}$), and maximal-intensity (> 3.0 $m \cdot s^{-2}$).

### 7.2.6 Perceived Wellness

Players were instructed to complete a modified self-report wellness questionnaire utilizing a commercially available web-based application (CoachMePlus, Buffalo, NY) on their smartphone device, on Game +1 and Game -2 throughout the in-season period. No physical activity took place on Game +1, however players were required to participate in medical evaluations, and were instructed to complete the questionnaire prior to the commencement of the evaluations. On Game -2, players were instructed to complete questionnaires prior to the morning training session. The modified wellness questionnaire, based upon earlier recommendations by Hooper et. al. (106), evaluated six subscales, including fatigue, soreness, stress, sleep quality, sleep quantity, and mood, on a 1-5 Likert scale (Figure 1). Although this modified questionnaire, similar to that utilized by McLean et. al. (153), has not been validated, traditional questionnaires with evidence of validity including RESTQ-Sport (128), ABQ (189), and DALDA (204) are often viewed as too lengthy and lacking in sport-specific focus to be utilized in applied settings. Simple composite measures have demonstrated sensitivity to changes in training load and recovery states of team sport athletes, and provide reliable and actionable data to coaches and performance staff (27, 86, 153). Players were instructed to respond as to how they were currently feeling.

**Figure 1. Perceived Wellness Questionnaire**

| Category | 5 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|
| **Fatigue** | Very Fresh | Fresh | Normal | More Tired Than Normal | Always Tired |
| **Sleep Quality** | Very Restful | Good | Difficulty Falling Asleep | Restless Sleep | Cannot Sleep |
| **General Soreness** | Feeling Great | Feeling Good | Normal | Increase in Soreness / Tightness | Very Sore |
| **Stress Levels** | Very Relaxed | Relaxed | Normal | Feeling Stressed | Very Stressed |
| **Mood** | Very Positive Mood | Generally Good Mood | Less Interested in Others / Activities than Normal | Aggravated / Short Tempered | Very Annoyed / Irritable |
| **How Many Hours Did You Sleep?** (Sleep Quantity) | More Than 10 Hrs. | 8-10 Hrs. | 6-8 Hrs. | 4-6 Hrs. | Less than 4 Hrs. |

### 7.2.7 Statistical Analyses

#### 7.2.7.1 Game +1 Model

A series of multi-level mixed linear regressions were used to determine the differential effect of specific game day movement metrics on perceived wellness ratings the following day (Game +1). Categorical outcomes were used to determine less favorable responses (1 and 2), neutral responses (3), and more favorable (4 and 5) responses to account for the possibility of non-linear relationships with varying outcomes. Each movement metric was associated with wellness ratings in each of the six subscales. Following the regression analyses, post-hoc tests were conducted to evaluate the pair-wise differentials of movement and their significance for each wellness rating (Tables 24-25). Significance in all tests was measured at three levels; $p<0.001$, $p<0.01$, and $p<0.05$. Adjusted predictions at the means were reported with their respective 95% confidence intervals. All statistical analyses were performed using Stata Statistical/Data Analysis Software (Stata 14 for Windows, version 14.1; StataCorp, College Station, TX, USA).

#### 7.2.7.2 Game -2 Model

A series of multi-level mixed linear regressions were used to determine the differential cumulative effects of specific movement metrics associated with Game -4 and Game -3 practice sessions on Game -2 perceived wellness. Categorical outcomes were used to determine less favorable responses (1 and 2), neutral responses (3), and more favorable (4 and 5) responses to account for the possibility of non-linear relationships with varying outcomes. Each movement metric was used to examine the relationship between an individual's Game -2 perceived wellness rating relative to their Game +1 perceived wellness rating. Following the regression analyses, post-hoc tests were conducted to evaluate the pair-wise differentials of each movement metric and its significance for each individual's Game -2 wellness rating compared to Game +1 (Tables 26-27). Significance in all tests was measured at three levels; $p<0.001$, $p<0.01$, and $p<0.05$. Adjusted predictions at the means are reported with their respective 95% confidence intervals. All statistical analyses were performed using Stata Statistical/Data Analysis Software (Stata 14 for Windows, version 14.1; StataCorp, College Station, TX, USA).

## 7.3 Results

### 7.3.1 Game +1 Perceived Wellness

Significant ($p<0.05$) differences in PL, low-, medium-, high-intensity distance and total distance, including acceleration and deceleration distance at all intensities resulting from competitive games on the preceding day, were demonstrated in players who rated their level of fatigue and soreness a 1 or 2, compared to those who rated it a 3, and those who rated it a 4 or 5. Significant ($p<0.05$) differences in sprint distance were also demonstrated in those who rated fatigue a 4 or 5 compared to those who rated fatigue a 1 or 2 (Table 24).

Individuals who reported a 3, 4, or 5 for perceived stress the day following competition demonstrated significantly ($p<0.05$) greater PL, low-, medium-intensity, and total distance, low- and medium-intensity deceleration distance, and medium- and high-intensity-acceleration distance than those who rated perceived stress a 1 or 2 (Table 25).

The only significant ($p<0.05$) findings for the subscale of sleep quality were for maximal-intensity deceleration distance between those whose ratings were a 1 or 2 vs a 3, and those who rated sleep quality a 1 or 2 vs. a 4 or 5 (Table 25). No significant differences in movement variables were demonstrated for subscales of mood and sleep quantity.

**Table 24. Game +1 Ratings of Perceived Fatigue and Soreness:** Line 1: Adjusted Predictions at the Means
*Line 2: Lower and Upper limits of 95% Confidence Interval*
[A] Significantly different ($p < 0.05$) for 1 or 2. [B] Significantly different ($p < 0.05$) for 3.
All distance measures are represented as meters.

| | Perceived Fatigue | | | Perceived Soreness | | |
|---|---|---|---|---|---|---|
| **Movement Variables** | **1 or 2** | **3** | **4 or 5** | **1 or 2** | **3** | **4 or 5** |
| **Total Distance** | 3839.6 (3686.1, 3993.1) | 3554.9 [A] (3426.2, 3683.5) | 3114.1 [AB] (2816.2, 3412.0) | 3817.9 (3694.1, 3941.8) | 3441.1 [A] (3426.2, 3683.5) | 3064.7 [AB] (2816.2, 3412.0) |
| **Low-Intensity Distance** | 3221.4 (3103.5, 3339.3) | 2988.8 [A] (2890.0, 3087.6) | 2665.2 [AB] (2436.4, 2894.0) | 3201.6 (3106.7, 3296.6) | 2908.5 [A] (2789.1, 3027.8) | 2594.2 [AB] (2333.1, 2855.4) |
| **Medium-Intensity Distance** | 391.7 (364.8, 418.6) | 361.4 (338.9, 383.9) | 293.0 [AB] (240.8, 345.2) | 387.2 (365.4, 409.1) | 347.4 [A] (319.9, 374.9) | 304.3 [A] (244.1, 364.4) |
| **High-Intensity Distance** | 162.7 (146.5, 178.9) | 149.8 (136.2, 163.4) | 114.0 [AB] (82.5, 145.5) | 167.2 (154.1, 180.3) | 134.2 [A] (117.7, 150.6) | 115.3 [A] (79.3, 151.3) |
| **Sprinting Distance** | 60.2 (50.9, 69.5) | 50.8 (42.9, 58.6) | 34.5 [A] (16.4, 52.6) | 58.1 (50.5, 65.6) | 46.5 (37.0, 56.1) | 44.1 (23.3, 65.0) |
| **Player Load** | 441.3 (425.7, 456.9) | 411.8 [A] (398.8, 424.9) | 365.5 [AB] (335.2, 395.7) | 441.0 (428.5, 453.5) | 398.2 [A] (382.5, 414.0) | 355.2 [AB] (320.8, 389.6) |
| **Low-Intensity Accel. Distance** | 1740.5 (1668.3, 1812.7) | 1610.7 [A] (1550.2, 1671.2) | 1395.3 [AB] (1255.1, 1535.4) | 1727.4 (1669.2, 1785.7) | 1567.7 [A] (1494.4, 1640.9) | 1351.7 [AB] (1191.4, 1511.9) |
| **Medium-Intensity Accel. Distance** | 101.7 (96.1, 107.3) | 91.8 [A] (87.1, 96.5) | 73.8 [AB] (63.0, 84.6) | 100.8 (96.3, 105.3) | 87.4 [A] (81.7, 93.1) | 73.9 [AB] (61.5, 86.4) |
| **High-Intensity Accel. Distance** | 52.4 (49.4, 55.3) | 48.2 (45.8, 50.7) | 39.5 [AB] (33.8, 45.2) | 52.5 (50.1, 54.9) | 45.3 [A] (42.3, 48.3) | 40.7 [A] (34,2, 47.3) |
| **Max-Intensity Accel. Distance** | 74.8 (70.6, 78.9) | 69.2 (65.7, 72.7) | 59.3 [AB] (51.2, 67.3) | 75.2 (71.8, 78.5) | 65.0 [A] (60.8, 69.2) | 61.0 [A] (51.8, 70.2) |
| **Low-Intensity Decel. Distance** | 1102.6 (1054.8, 1150.5) | 1014.5 [A] (974.3, 1054.6) | 879.6 [AB] (786.7, 972.6) | 1093.2 (1054.5, 1131.9) | 984.9 [A] (936.2, 1033.5) | 859.2 [AB] (752.8, 965.6) |
| **Medium-Intensity Decel. Distance** | 72.5 (67.9, 77.0) | 65.6 [A] (61.8, 69.4) | 52.2 [AB] (43.4, 61.0) | 72.3 (68.6, 76.9) | 61.7 [A] (57.1, 66.3) | 53.0 [AB] (42.9, 63.1) |
| **High-Intensity Decel. Distance** | 27.4 (25.4, 29.5) | 24.5 [A] (22.8, 26.1) | 19.5 [AB] (15.6, 23.4) | 27.5 (25.9, 29.1) | 22.6 [A] (20.6, 24.7) | 19.8 [A] (15.3, 24.2) |
| **Max-Intensity Decel. Distance** | 28.1 (25.9, 30.3) | 24.6 [A] (22.7, 26.5) | 19.3 [AB] (15.0, 23.7) | 27.9 (26.0, 29.7) | 22.7 [A] (20.5, 25.0) | 20.8 [A] (15.8, 25.7) |

**Table 25. Game +1 Ratings of Perceived Stress and Sleep Quality:** Line 1: Adjusted Predictions at the Means
*Line 2: Lower and Upper limits of 95% Confidence Interval*
$^{A}$ Significantly different ($p < 0.05$) for 1 or 2. $^{B}$ Significantly different ($p < 0.05$) for 3.
All distance measures are represented as meters.

| | **Perceived Stress** | | | **Perceived Sleep Quality** | | |
|---|---|---|---|---|---|---|
| **Movement Variables** | **1 or 2** | **3** | **4 or 5** | **1 or 2** | **3** | **4 or 5** |
| **Total Distance** | 3314.8 (3055.4, 3574.3) | 3647.9 $^{A}$ (3512.5, 3783.3) | 3729.9 $^{A}$ (3551.3, 3908.6) | 3761.0 (3540.6, 3981.4) | 3628.6 (3443.4, 3813.7) | 3552.1 (3405.8, 3698.3) |
| **Low-Intensity Distance** | 2812.7 (2613.3, 3012.1) | 3070.1 $^{A}$ (2966.0, 3174.2) | 3126.1 $^{A}$ (2988.8, 3263.3) | 3160.7 (2991.5, 3329.9) | 3073.6 (2931.5, 3215.8) | 2977.9 (2865.6, 3090.2) |
| **Medium-Intensity Distance** | 315.8 (270.8, 360.9) | 369.3 $^{A}$ (3458., 392.8) | 385.7 $^{A}$ (354.7, 416.7) | 373.2 (334.9, 411.5) | 359.6 (327.4, 391.8) | 367.0 (341.5, 392.4) |
| **High-Intensity Distance** | 129.6 (102.4, 156.7) | 153.1 (138.9, 167.3) | 158.6 (139.9, 177.3) | 164.3 (141.3, 187.3) | 145.5 (126.2, 164.8) | 148.4 (133.1, 163.6) |
| **Sprinting Distance** | 52.1 (36.5, 67.7) | 51.7 (43.5, 59.8) | 54.6 (43.9, 65.4) | 58.2 (45.1, 71.4) | 46.9 (35.9, 58.0) | 53.8 (45.1, 62.5) |
| **Player Load** | 380.2 (353.9, 406.4) | 419.5 $^{A}$ (405.8, 433.2) | 435.7 $^{A}$ (417.6, 453.7) | 432.9 (410.5, 455.3) | 415.9 (397.0, 434.7) | 413.7 (398.8, 428.6) |
| **Low-Intensity Accel. Distance** | 1510.7 (1388.4, 1632.9) | 1644.2 (1580.4, 1708.0) | 1693.9 $^{A}$ (1609.8, 1778.1) | 1713.4 (1609.8, 1817.0) | 1643.4 (1556.3, 1730.5) | 1602.7 (1533.9, 1671.5) |
| **Medium-Intensity Accel. Distance** | 83.4 (73.9, 92.9) | 94.9 $^{A}$ (90.0, 99.9) | 97.2 $^{A}$ (90.7, 103.7) | 100.1 (92.1, 108.1) | 93.3 (86.5, 100.0) | 91.2 (85.9, 96.5) |
| **High-Intensity Accel. Distance** | 43.2 (38.3, 48.2) | 49.7 $^{A}$ (47.1, 52.3) | 50.7 $^{A}$ (47.2, 54.1) | 50.9 (46.6, 55.1) | 49.2 (45.7, 52.8) | 47.9 (45.1, 50.7) |
| **Max-Intensity Accel. Distance** | 63.2 (56.3, 70.2) | 71.4 $^{A}$ (67.8, 75.0) | 72.3 (67.5, 77.1) | 74.6 (68.7, 80.5) | 70.1 (65.1, 75.0) | 68.5 (64.6, 72.5) |
| **Low-Intensity Decel. Distance** | 951.8 (870.8, 1032.9) | 1037.2 (995.9, 1079.5) | 1072.0 $^{A}$ (1016.2, 1127.8) | 1059.2 (990.3, 1128.0) | 1036.8 (978.9, 1094.6) | 1023.2 (977.5, 1068.9) |
| **Medium-Intensity Decel. Distance** | 58.8 (51.1, 66.5) | 67.8 $^{A}$ (63.8, 71.8) | 69.5 $^{A}$ (64.2, 74.8) | 69.9 (63.3, 76.4) | 66.8 (61.3, 72.3) | 65.6 (61.3, 69.9) |
| **High-Intensity Decel. Distance** | 21.9 (18.6, 25.3) | 25.7 (23.9, 27.4) | 25.9 (23.5, 28.2) | 27.0 (24.2, 29.9) | 24.9 (22.5, 27.3) | 24.3 (22.4, 26.2) |
| **Max-Intensity Decel. Distance** | 22.3 (18.5, 26.0) | 25.6 (23.7, 27.6) | 26.7 (24.1, 29.3) | 29.1 (25.9, 32.3) | 24.5 $^{A}$ (21.8, 27.2) | 24.3 $^{A}$ (22.2, 26.4) |

### 7.3.2 Game -2 Perceived Wellness

Individuals who rated their perceived fatigue a 4 or 5 on both Game +1 and Game -2 accumulated significantly ($p<0.05$) less high-intensity deceleration and maximal-intensity acceleration distance on Game -4 and Game -3 practices than those who rated fatigue a 1 or 2 on Game +1 and improved to a 3 on Game -2, and those who reported a 1, 2, or 3 on Game +1 and improved to 4 or 5 on Game -2 (Table 26).

**Table 26. Game -2 Ratings of Perceived Fatigue:** Line 1: Adjusted Cumulative Game -5 – Game -3 Practice Session Predictions at the Means
*Line 2: Lower and Upper limits of 95% Confidence Interval*
[A] Significantly different ($p < 0.05$) for 1 or 2 that were better than Game +1. [B] Significantly different for 1 or 2 that were same or worse than Game +1. [C] Significantly different for a 3 that were better than Game +1. [D] Significantly different for a 3 that were same or worse than Game +1. [E] Significantly different for 4 or 5 that were better than Game +1.
All distance measures are represented as meters.

| Movement Variables | 1 or 2 on Game -2 | | 3 on Game -2 | | 4 or 5 on Game -2 | |
|---|---|---|---|---|---|---|
| | Better than Game +1 | Same or Worse than Game +1 | Better than Game +1 | Same or Worse than Game +1 | Better than Game +1 | Same or Worse than Game +1 |
| **Total Distance** | 6349.5 (5521.9, 7177.0) | 6479.0 (6339.8, 6618.2) | 6560.7 (6363.8, 6757.5) | 6381.4 6267.2, 6495.6) | 6501.7 (6280.6, 6722.9) | 6194.8 (5846.7, 6542.8) |
| **Low-Intensity Distance** | 5071.5 (4434.6, 5708.4) | 5224.6 (5117.6, 5331.6) | 5270.6 (5119.3, 5422.0) | 5110.8 (5022.9, 5198.7) | 5207.2 (5037.2, 5377.2) | 5015.4 (4747.5, 5283.3) |
| **Medium-Intensity Distance** | 844.7 (697.0, 992.4) | 816.2 (791.3, 841.1) | 840.3 (805.1, 875.5) | 823.8 (803.5, 844.2) | 848.5 (809.1, 888.0) | 761.6 [EC] (699.7, 823.5) |
| **High-Intensity Distance** | 370.0 (278.2, 461.8) | 356.5 (341.0, 371.9) | 376.3 (354.3, 398.3) | 367.1 (354.5, 379.8) | 371.5 (346.9, 396.1) | 334.6 (296.0, 373.2) |
| **Sprinting Distance** | 73.7 (41.5, 105.9) | 71.7 (66.3, 77.1) | 74.2 (66.5, 81.9) | 75.7 (71.3, 80.2) | 80.1 (71.5, 88.7) | 74.7 (60.9, 88.4) |
| **Player Load** | 801.5 (720.3, 882.6) | 801.4 (787.8, 815.0) | 813.5 (794.2, 832.7) | 793.7 (782.5, 804.8) | 800.3 (778.8, 821.9) | 783.1 (749.1, 817.1) |
| **Low-Intensity Accel. Distance** | 3000.2 (2619.9, 3380.5) | 2988.0 (2923.9, 3052.1) | 3026.3 (2935.8, 3116.8) | 2950.0 (2897.5, 3002.4) | 3005.4 (2903.8, 3107.0) | 2833.9 (2673.2, 2994.7) |
| **Medium-Intensity Accel. Distance** | 191.8 (165.1, 218.5) | 189.9 (185.3, 194.4) | 193.8 (187.5, 200.1) | 189.7 (186.0, 193.4) | 193.7 (186.5, 200.8) | 178.8 [EC] (167.6, 190.1) |
| **High-Intensity Accel. Distance** | 106.2 (91.2, 121.3) | 105.1 (102.6, 107.7) | 108.4 (104.8, 111.9) | 104.9 (102.8, 106.9) | 107.9 (103.9, 111.9) | 101.1 (94.7, 107.4) |
| **Max-Intensity Accel. Distance** | 189.4 (164.8, 214.0) | 185.6 (181.4, 189.8) | 189.9 (184.0, 195.7) | 185.1 (181.7, 188.5) | 188.3 (181.8, 194.9) | 175.7 [EC] (165.4, 186.0) |
| **Low-Intensity Decel. Distance** | 2294.9 (2032.6, 2557.2) | 2271.7 (2227.4, 2315.9) | 2304.5 (2242.0, 2367.0) | 2269.4 (2233.2, 2305.5) | 2294.9 (2225.0, 2364.8) | 2172.8 (2061.8, 2283.9) |
| **Medium-Intensity Decel. Distance** | 173.0 (147.6, 198.3) | 168.7 (164.4, 173.0) | 173.7 (167.7, 179.7) | 170.2 (166.7, 173.7) | 172.1 (165.3, 178.9) | 159.0 [EC] (148.4, 169.7) |
| **High-Intensity Decel. Distance** | 65.0 (53.5, 59.7) | 63.1 (61.1, 65.0) | 66.0 (63.2, 68.7) | 63.9 (62.4, 65.5) | 66.0 (63.0, 69.1) | 59.0 [EC] (54.1, 63.8) |
| **Max-Intensity Decel. Distance** | 48.4 (37.1, 59.7) | 47.0 (45.1, 48.9) | 49.3 (46.6, 52.0) | 46.8 (45.2, 48.3) | 48.9 (45.9, 51.9) | 44.1 (39.4, 48.9) |

When comparing players whose rating of perceived soreness improved from Game +1 to Game -2, those who rated soreness a 4 or 5 on Game -2, accumulated significantly ($p<0.05$) more PL on Game -4 and Game -3 than those who rated soreness a 3 on Game -2. Individuals whose perceived soreness was a 3 on Game -2 and the same or higher score on Game +1 achieved significantly ($p<0.05$) less PL than those whose perceived rating of soreness was a 3 on Game -2 but lower (1 or 2) on Game +1. Players who rated soreness a 4 or 5 on both Game +1 and Game -2 had significantly ($p<0.05$) higher cumulative PL resulting from Game -4 and Game -3 practices than those who rated soreness a 4 or 5 on Game -2 and a 1, 2, or 3 on Game +1. Significantly ($p<0.05$) more total-, maximal- and high-intensity acceleration and deceleration distance was accumulated on Game -4 and Game -3 by those who rated soreness a 4 or 5 on both Game +1 and Game -2, compared to those whose rating was a 3 on Game -2 and the same or higher on Game +1 (Table 27).

**Table 27. Game -2 Ratings of Perceived Soreness:** Line 1: Adjusted Cumulative Game -5 – Game -3 Practice Session Predictions at the Means
*Line 2: Lower and Upper limits of 95% Confidence Interval*
$^{A}$ Significantly different ($p < 0.05$) for 1 or 2 that were better than Game +1. $^{B}$ Significantly different for 1 or 2 that were same or worse than Game +1. $^{C}$ Significantly different for a 3 that were better than Game +1. $^{D}$ Significantly different for a 3 that were same or worse than Game +1. $^{E}$ Significantly different for 4 or 5 that were better than Game +1.
All distance measures are represented as meters.

| Movement Variables | 1 or 2 on Game -2 | | 3 on Game -2 | | 4 or 5 on Game -2 | |
|---|---|---|---|---|---|---|
| | Better than Game +1 | Same or Worse than Game +1 | Better than Game +1 | Better than Game +1 | Same or Worse than Game +1 | Better than Game +1 |
| **Total Distance** | 6477.8 (6211.4, 6744.3) | 6490.1 (6367.2, 6613.1) | 6503.2 (6355.5, 6651.0) | 6299.8 (6162.6, 6437.0) | 6337.2 (6101.8, 6572.7) | 6689.4 $^{E}$ (6354.0, 7024.9) |
| **Low-Intensity Distance** | 5182.6 (4977.1, 5388.1) | 5222.7 (5127.8, 5317.6) | 5218.5 (5104.6, 5332.5) | 5065.5 (4959.7, 5171.2) | 5090.9 (4909.4, 5272.3) | 5344.6 $^{D}$ (5086.5, 5602.7) |
| **Medium-Intensity Distance** | 834.4 (786.7, 882.0) | 827.8 (805.8, 849.8) | 833.1 (806.6, 859.6) | 800.9 (776.4, 825.4) | 810.4 (768.3, 852.5) | 880.1 $^{D}$ (820.2, 940.0) |
| **High-Intensity Distance** | 370.1 (340.4, 399.8) | 365.7 (352.0, 379.4) | 369.8 (353.8, 386.3) | 354.1 (338.7, 369.4) | 349.9 (323.6, 376.2) | 390.7 (353.2, 428.2) |
| **Sprinting Distance** | 75.1 (64.7, 85.5) | 72.6 (67.8, 77.4) | 75.9 (70.1, 81.6) | 74.6 (69.3, 80.0) | 79.6 (70.3, 88.8) | 78.6 (65.5, 91.7) |
| **Player Load** | 803.6 (777.5, 829.7) | 805.2 (793.2, 817.1) | 808.2 (793.9, 822.4) | 782.3 $^{CB}$ (769.0, 795.6) | 781.5 $^{C}$ (758.7, 804.3) | 829.5 $^{DE}$ (797.0, 861.9) |
| **Low-Intensity Accel. Distance** | 3000.7 (2878.0, 3123.5) | 2994.3 (2937.7, 3051.0) | 2996.3 (2928.2, 3064.5) | 2910.9 (2847.7, 2974.1) | 2930.7 (2822.2, 3039.1) | 3081.1 $^{D}$ (2926.9, 3235.3) |
| **Medium-Intensity Accel. Distance** | 191.7 (183.1, 200.2) | 191.1 (187.1, 195.0) | 192.4 (187.7, 197.2) | 185.6 (181.2, 190.0) | 188.1 (180.5, 195.7) | 201.1 $^{D}$ (190.3, 212.0) |
| **High-Intensity Accel. Distance** | 106.8 (101.9, 111.6) | 106.1 (103.9, 108.3) | 106.6 (104.0, 109.3) | 102.9 (100.4, 105.4) | 104.8 (100.5, 109.1) | 111.6 $^{D}$ (105.5, 117.7) |
| **Max-Intensity Accel. Distance** | 188.0 (180.1, 195.9) | 186.0 (182.3, 189.6) | 188.9 (184.5, 193.3) | 181.4 $^{C}$ (177.3, 185.4) | 183.2 (176.2, 190.2) | 197.0 $^{DE}$ (187.0, 207.0) |
| **Low-Intensity Decel. Distance** | 2302.0 (2217.5, 2386.4) | 2284.3 (2245.3, 2323.3) | 2295.0 (2248.1, 2341.8) | 2230.1 (2186.7, 2273.6) | 2236.0 (2161.4, 2310.6) | 2345.7 $^{D}$ (2239.3, 2452.1) |
| **Medium-Intensity Decel. Distance** | 172.2 (164.0, 180.3) | 170.3 (166.5, 174.1) | 172.2 (167.7, 176.7) | 165.9 (161.7, 170.1) | 166.8 (159.6, 174.0) | 179.3 $^{D}$ (168.9, 189.6) |
| **High-Intensity Decel. Distance** | 64.7 (60.9, 68,4) | 63.6 (61.9, 65.3) | 65.3 (63.2, 67.3) | 62.5 (60.6, 64.4) | 62.9 (59.6, 66.3) | 68.9 $^{DE}$ (64.2, 73.6) |
| **Max-Intensity Decel. Distance** | 47.7 (44.0, 51.3) | 47.3 (45.6, 48.9) | 48.3 (46.3, 50.3) | 45.7 (43.8, 47.6) | 47.2 (44.0, 50.5) | 51.6 $^{D}$ (47.0, 56.2) |

Players who rated perceived stress a 4 or 5 on both Game +1 and Game -2 accumulated significantly ($p<0.05$) greater PL, total-, sprint- and maximal-acceleration and deceleration distance on Game -4 and Game -3 than those who rated stress a 1, 2, or 3 on Game +1 and improved to a 4 or 5 on Game -2, and those who rated stress a 3, 4, or 5 on Game +1 and increased to a 3 on Game -2. Individuals who rated perceived stress a 4 or 5 on both Game +1 and Game -2 achieved significantly ($p<0.05$) less total distance on Game -4 and Game -3 than those whose perceived stress was a 1 or 2 on Game -2 and the same or higher on Game +1 (Table 28). Players who rated sleep quality a 4 or 5 on both Game +1 and Game -2 accrued significantly ($p<0.05$) more sprint distance on Game -4 and Game -3 practice sessions than those who rated sleep quality a 3 on Game -2 and a 1 or 2 on Game +1 (Table 29).

**Table 28. Game -2 Ratings of Perceived Stress:** Line 1: Adjusted Cumulative Game -5 – Game -3 Practice Session Predictions at the Means
*Line 2: Lower and Upper limits of 95% Confidence Interval*
[A] Significantly different ($p < 0.05$) for 1 or 2 that were better than Game +1. [B] Significantly different for 1 or 2 that were same or worse than Game +1. [C] Significantly different for a 3 that were better than Game +1. [D] Significantly different for a 3 that were same or worse than Game +1. [E] Significantly different for 4 or 5 that were better than Game +1.
All distance measures are represented as meters.

| Movement Variables | 1 or 2 on Game -2 | | 3 on Game -2 | | 4 or 5 on Game -2 | |
|---|---|---|---|---|---|---|
| | Better than Game +1 | Same or Worse than Game +1 | Better than Game +1 | Same or Worse than Game +1 | Better than Game +1 | Same or Worse than Game +1 |
| **Total Distance** | - | 6516.1 (6324.2, 6708.0) | 6366.4 (6114.0, 6618.8) | 6394.5 (6287.8, 6501.2) | 6215.4 [B] (6028.8, 6402.0) | 6649.4 [DE] (6454.7, 6844.0) |
| **Low-Intensity Distance** | - | 5265.6 (5116.7, 5414.4) | 5092.0 (4896.5, 5287.5) | 5151.9 (5069.4, 5234.5) | 5013.2 [B] (4868.9, 5157.6) | 5285.8 [E] (5135.2, 5436.3) |
| **Medium-Intensity Distance** | - | 812.1 (778.1, 846.1) | 831.4 (786.6, 876.2) | 809.0 (790.1, 828.0) | 758.8 (752.6, 819.0) | 882.0 [BDE] (847.3, 916.6) |
| **High-Intensity Distance** | - | 362.5 (341.2, 383.7) | 372.0 (344.0, 400.0) | 354.3 (342.5, 366.2) | 346.8 (326.1, 367.5) | 391.9 [DE] (370.3, 413.5) |
| **Sprinting Distance** | - | 74.2 (66.7, 81.6) | 76.4 (66.5, 86.2) | 72.4 (68.2, 76.6) | 68.9 (61.6, 76.2) | 83.5 [DE] (75.9, 91.2) |
| **Player Load** | - | 797.9 (779.0, 816.7) | 794.8 (770.0, 819.6) | 795.1 (784.7, 805.6) | 780.0 (761.6, 798.3) | 820.9 [DE] (801.9, 839.9) |
| **Low-Intensity Accel. Distance** | - | 2975.8 (2886.9, 3064.7) | 2949.6 (2832.9, 3066.3) | 2950.5 (2901.0, 3000.0) | 2895.4 (2809.1, 2981.7) | 3072.0 [DE] (2980.9, 3163.0) |
| **Medium-Intensity Accel. Distance** | - | 189.8 (183.7, 196.0) | 189.1 (181.0, 197.2) | 188.7 (185.3, 192.1) | 181.3 (175.3, 187.2) | 199.6 [DE] (193.3, 205.9) |
| **High-Intensity Accel. Distance** | - | 105.3 (101.8, 108.8) | 105.6 (101.1, 110.2) | 104.3 (102.4, 106.2) | 101.5 (98.2, 104.9) | 111.0 [BDE] (107.4, 114.5) |
| **Max-Intensity Accel. Distance** | - | 186.3 (180.6, 192.1) | 186.9 (179.4, 194.5) | 183.7 (180.5, 186.9) | 180.5 (175.0, 186.1) | 192.6 [DE] (186.8, 198.4) |
| **Low-Intensity Decel. Distance** | - | 2267.5 (2206.6, 2328.4) | 2254.4 (2174.5, 2334.3) | 2253.5 (2219.7, 2287.4) | 2211.6 (2152.6, 2270.6) | 2360.2 [DE] (2297.7, 2422.7) |
| **Medium-Intensity Decel. Distance** | - | 169.0 (163.2, 174.9) | 171.0 (163.4, 178.7) | 167.6 (164.4, 170.9) | 162.5 (156.8, 168.1) | 179.1 [BDE] (173.1, 185.0) |
| **High-Intensity Decel. Distance** | - | 63.3 (60.6, 65.9) | 64.2 (60.6, 67.7) | 63.1 (61.6, 64.6) | 61.4 (58.7, 64.0) | 67.6 [DE] (64.9, 70.4) |
| **Max-Intensity Decel. Distance** | - | 47.3 (44.7, 49.9) | 48.6 (45.1, 52.0) | 46.4 (44.9, 47.8) | 44.7 (42.1, 47.2) | 50.4 [DE] (47.7, 53.0) |

**Table 29. Game -2 Ratings of Perceived Sleep Quality:** Line 1: Adjusted Cumulative Game -5 – Game -3 Practice Session Predictions at the Means
*Line 2: Lower and Upper limits of 95% Confidence Interval*
[A] Significantly different ($p < 0.05$) for 1 or 2 that were better than Game +1. [B] Significantly different for 1 or 2 that were same or worse than Game +1. [C] Significantly different for a 3 that were better than Game +1. [D] Significantly different for a 3 that were same or worse than Game +1. [E] Significantly different for 4 or 5 that were better than Game +1.
All distance measures are represented as meters.

| Movement Variables | 1 or 2 on Game -2 | | 3 on Game -2 | | 4 or 5 on Game -2 | |
|---|---|---|---|---|---|---|
| | Better than Game +1 | Same or Worse than Game +1 | Better than Game +1 | Same or Worse than Game +1 | Better than Game +1 | Same or Worse than Game +1 |
| **Total Distance** | 6501.4 (5838.1, 7164.8) | 6382.6 (6204.6, 6560.5) | 6172.8 (5878.5, 6467.2) | 6429.8 (6298.1, 6561.4) | 6454.2 (6310.7, 6597.7) | 6506.0 (6370.8, 6641.2) |
| **Low-Intensity Distance** | 5269.8 (4759.9, 5779.8) | 5123.3 (4986.4, 5260.3) | 4964.3 (4737.9, 5910.6) | 5158.4 (5057.2, 5259.6) | 5164.6 (5054.2, 5275.1) | 5248.4 [C] (5144.2, 5352.6) |
| **Medium-Intensity Distance** | 799.0 (680.0, 918.1) | 813.1 (781.0, 845.1) | 796.4 (743.8, 849.0) | 822.1 (798.5, 845.7) | 837.5 (811.8, 863.2) | 824.0 (799.8, 848.2) |
| **High-Intensity Distance** | 350.6 (277.1, 424.1) | 358.7 (338.9, 378.6) | 340.3 (307.5, 373.1) | 367.1 (352.5, 381.8) | 373.3 (357.4, 389.2) | 360.2 (345.2, 375.2) |
| **Sprinting Distance** | 77.3 (51.7, 102.9) | 72.9 (66.0, 79.8) | 62.5 (51.1, 73.8) | 76.0 [C] (70.9, 81.1) | 74.9 (69.3, 80.4) | 76.6 [C] (71.3, 81.8) |
| **Player Load** | 816.1 (750.2, 882.0) | 796.3 (778.9, 813.7) | 774.9 (746.1, 803.6) | 799.8 (786.9, 812.6) | 803.5 (789.4, 817.5) | 799.4 (786.2, 812.6) |
| **Low-Intensity Accel. Distance** | 3039.9 (2733.8, 3346.0) | 2964.2 (2882.3, 3046.1) | 2865.8 (2730.4, 3001.3) | 2981.9 (2921.3, 3042.4) | 2993.4 (2927.3, 3059.4) | 2967.5 (2905.3, 3029.7 |
| **Medium-Intensity Accel. Distance** | 189.6 (168.1, 211.2) | 188.6 (182.8, 194.3) | 184.4 (174.9, 193.9) | 189.8 (185.5, 194.1) | 193.0 (188.3, 197.6) | 190.2 (185.8, 194.6) |
| **High-Intensity Accel. Distance** | 104.6 (92.5, 116.6) | 104.5 (101.3, 107.8) | 101.4 (96.0, 106.8) | 105.8 (103.4, 108.2) | 106.5 (103.9, 109.1) | 105.9 (103.4, 108.4) |
| **Max-Intensity Accel. Distance** | 184.1 (164.4, 203.9) | 184.3 (179.0, 189.6) | 179.0 (170.3, 187.8) | 186.6 (182.7, 190.5) | 187.9 (183.6, 192.2) | 185.4 (181.3, 189.4) |
| **Low-Intensity Decel. Distance** | 2261.0 (2050.4, 2471.5) | 2263.9 (2207.4, 2320.4) | 2208.0 (2114.7, 2301.3) | 2277.9 (2236.2, 2319.6) | 2287.9 (2242.3, 2333.4) | 2271.2 (2228.4, 2314.1) |
| **Medium-Intensity Decel. Distance** | 165.1 (144.8, 185,4) | 167.3 (161.8, 172.8) | 164.8 (155.8, 173.8) | 170.2 (166.1, 174.2) | 172.9 (168.5, 177.3) | 169.3 (165.2, 173.5) |
| **High-Intensity Decel. Distance** | 62.5 (53.2, 71.8) | 62.8 (60.3, 65.3) | 60.7 (56.6, 64.8) | 64.5 (62.7, 66.4) | 65.6 [C] (63.6, 67.6) | 63.2 (61.3, 65.1) |
| **Max-Intensity Decel. Distance** | 48.1 (39.1, 57.1) | 46.9 (44.5, 49.4) | 43.4 (39.4, 47.4) | 47.4 (45.6, 49.2) | 48.4 [C] (46.5, 50.4) | 47.1 (45.3, 48.9) |

### 7.4 Discussion

The aims of the present study were to assess recovery, utilizing a modified wellness questionnaire, to determine which GPS-derived game-day variables influenced perceived wellness the following day, and to determine the impact of in-season weekly practice sessions on subjective markers of perceived wellness two days prior to games. The results of the present study contribute novel insight into the perceived wellness associated with practice and competitive loads experienced by NCAA division I college football players throughout in-season period and the implementation of wellness questionnaires within an applied, high-performance setting. The results confirm our hypothesis that differences in perceived wellness were associated with significant differences in individual movement characteristics attributed to practice and competition. The most notable findings were significantly ($p<0.05$) less PL, low-intensity, medium-intensity, high-intensity, and total distance, and acceleration and deceleration distance at all intensities, associated with competition, in those with more favorable ratings of perceived fatigue and soreness the day following games. Additionally, individuals who reported more favorable perceived stress the day following competition demonstrated significantly ($p<0.05$) greater PL, low-intensity, medium-intensity, and total distance, low-intensity and medium-intensity deceleration distance, and acceleration distance at all intensities than individuals who reported the least favorable ratings of perceived stress. Data from the present study provide an increased understanding of the impact of specific game-day movement variables on post-game perceptual wellness, and support the implementation of a perceived wellness questionnaire to quantify perceptual recovery following NCAA division I football games.

Individuals who accrued significantly ($p<0.05$) less PL, running distance at all intensities, and deceleration and acceleration distance at all intensities during NCAA division I football games, reported more favorable ratings of perceived fatigue the day following the game. Similar findings with respect to perceived soreness the day following games were demonstrated by significantly ($p<0.05$) less PL, running distance at all intensities, except for sprint distance, and acceleration and deceleration at all intensities in individuals who reported more favorable ratings. Individuals who reported more favorable perceived stress responses the day following games demonstrated significantly ($p<0.05$) greater movement demands associated with competition than those who rated perceived stress less favorably. The results of the present study suggest that increased movement demands resulting from competition may be directly associated with a less favorable perceived fatigue and soreness response the day following games. The perceived stress response appears to differ from both the fatigue and soreness response, resulting in more favorable perceived stress responses associated with increased movement demands. These data illustrate that movement characteristics associated with NCAA division I football games reflect individual perceptions of fatigue, soreness, and stress, and support the integration of perceived wellness measures as part of a comprehensive athlete monitoring program.

The high-intensity movement demands, and the frequency and intensity of positional impacts and rapid changes of direction that characterize participation in NCAA division I football games have been reported, are associated with substantial physical demands, and may contribute to increased fatigue and soreness following games (235, 236). Comparing the results of the present study with previous examinations is problematic due to the paucity of similar investigations in NCAA division I football. An examination by Fullagar et.al. (72) of the time course of perceptual recovery following NCAA division I football games demonstrated less favorable ratings of perceived soreness and overall wellness that persisted for up to four days following competition. While the results of Fullagar et. al. (72) shed new light on perceptions of wellness associated with NCAA division I football seasons, it did not examine perceived wellness the day following competition or quantify the game day movement demands associated with the wellness response.

Similar findings of increased perceived soreness and fatigue one day following contact team-sport competition have been demonstrated by researchers (153, 230) who utilized a questionnaire similar to the one in the present study, and reported significant ($p<0.01$) increases in fatigue and soreness ratings one day following Rugby League competition, when compared to pre-competition values. The scope of these studies, however, did not include the utilization of microtechnology to assess competitive movement demands to determine which GPS-derived movement variables may influence the differential ratings of perceived wellness the following day. While fatigue and soreness following intense team-sport competition may be expected, the present study represents a novel investigation into which GPS-derived gameday movement variables influence perceived wellness the following day. As part of a judicious athlete monitoring program, the objective quantification of external loads associated with practice and competition, alongside a subjective quantification of the athlete's physiological and psychological response to these loads, appears prudent (97). Previous research (26) has suggested the focus on general recovery modalities (sleep, social recovery, general well-being) in addition to sport-specific recovery activities during the season, may be useful to team-sport athletes, supporting the implementation of recovery modalities for improvements in perceived wellness. Clear guidelines on the modification of training loads in response to unfavorable perceptual responses do not exist (144), and as such, performance coaches should judiciously monitor the perceptual responses of athletes following competition and take appropriate measures including the implementation of recovery protocols and the modification of subsequent practice session when deemed prudent.

In the present study, several GPS-derived variables were able to differentiate individuals whose rating of perceptual stress was a 4 or 5 vs. a 1 or 2, and those who rated stress a 3 vs. a 1 or 2. Data indicated more favorable perceived stress responses with increases in game-day exercise demands. These findings are in agreement with the results reported by Hartwig et. al. (100) which demonstrated an inverse relationship between training volumes and perceptual stress ratings in Rugby Union players during the in-season period, but are in contrast with pre-season research (27) in Australian rules football, which demonstrated a negative effect of increased training loads on perceived stress ratings the following day. These data may indicate a directional relationship between the perceptual stress response and movement demands associated with intensified pre-season training camps in contact team-sport athletes, and an inverse relationship for competitive games, perhaps due to psychological factors unaccounted for, including self-satisfaction (100). In division I college football players, both physical and psychological stress have been associated with injury occurrence (152, 182), and consequently, the inclusion of the stress subscale as part of the athlete wellness monitoring program may be advantageous in decreasing the likelihood of maladaptation resulting from all sources of stress accompanying participation in division I college football.

The present study also investigated perceptual wellness two days prior to games to evaluate the time-course of perceived recovery and to assess the impact of in-season weekly practice sessions on subjective markers of perceived wellness preceding competition. While several significant unidirectional relationships were demonstrated between GPS-derived movement demands of competition and perceived fatigue on Game +1, similar significant unidirectional relationships were not established when examining the impact of Game -4 and Game -3 practice sessions on Game -2 perceived fatigue. Individuals who accumulated significantly ($p<0.05$) greater medium-intensity and high-intensity deceleration and medium-intensity and maximal-intensity acceleration distance on Game -4 and Game -3 practice sessions experienced an improvement, indicated by higher scores, in perceived fatigue on Game -2. These improvements were seen in individuals who rated perceived fatigue a 1 or 2 on Game +1 and improved to a 3 on Game -2, and those who were a 1, 2 or 3 on Game +1 and improved to a 4 or 5 on Game -2, when compared to individuals who rated perceived fatigue a 4 or 5 on both Game +1 and Game -2. The results of Game -2 assessments of perceived fatigue in the present study are supported by previous research (100) in Rugby Union players which demonstrated more favorable recovery scores in players who had the highest training and physical activity volumes during the in-season period. Data from the present study suggest that individuals with more unfavorable, or lower, ratings of perceived fatigue on Game +1 are not hindered by increased practice loads on Game -4 and Game -3, but may actually experience improvements in perceived fatigue ratings on Game -2. It is also plausible to assume that individuals who experienced increased perceived fatigue on Game +1 may have engaged in recovery modalities in conjunction with programmed physical activities, resulting in more favorable perceived fatigue ratings on Game -2.

A lack of unidirectional findings of Game -2 perceived wellness was demonstrated for the subscales of perceived soreness and stress. Individuals who rated perceived soreness a 4 or 5 on both Game +1 and Game -2 accumulated significantly ($p<0.05$) greater PL, high-intensity deceleration distance and maximal-acceleration distance in Game -4 and Game -3 practice sessions than those whose soreness rating improved from Game +1 to Game -2, and those whose rating was the same or became worse from Game +1 to Game -2. Similar to soreness, the subscale of stress demonstrated significantly ($p<0.05$) greater PL, total, high-intensity, and sprint distance, and maximal- and high-intensity acceleration and deceleration distance for individuals rating perceived stress a 4 or 5 on both Game +1 and Game -2 than those whose perceived stress improved from Game +1 to Game -2, and those whose rating was the same or became worse from Game +1 to Game -2. Limited research (72) in NCAA division I college football players makes comparison of the present study with previous investigations problematic. It is unclear whether differences in practice loads in the present study were responsible for improvements demonstrated in some wellness subscales, or if other factors including days until competition and under-reporting unfavorable responses (63) in attempt to appear better or more well-adjusted, played a role. An examination (83) of in-season perceptual wellness in Australian football players has indicated that days-to-game was a significant coefficient for wellness. Similar results have been demonstrated in Rugby League players (153) with shorter micro-cycles between competition being associated with improved wellness, suggesting that players' perception of wellness is related to days-to-game. Psychological factors, including motivation and focus of an athlete on the impending game, may override negative physiological symptoms, resulting in players perceiving themselves as recovered and physically prepared for competition (86). The possibility of these results being confounded via conscious bias associated with Game -2 questionnaires cannot be underestimated. This is often the result of an individual responding in a socially desirable manner, typically over-reporting positive responses and under-reporting negative or unfavorable responses (208). In a college football player, this may manifest as overrating wellness on Game -2 in attempt present their physical state more favorably to the coaching staff, despite possible negative physical symptoms associated with the cumulative loading of the Game -4 and Game -3 practice sessions. It is plausible that these factors may have contributed to the lack of unidirectional findings associated with the Game -2 questionnaires, however similar investigations have not been undertaken in NCAA division I college football players.

The results of the present study provide novel insight to the physical and psychological responses associated with participation in NCAA division I football games and in-season practice sessions.  Significant differences in volumes and intensities of GPS and IA movement variables were reported in athletes who responded more or less favorably on perceived wellness measures.  The use of a customized wellness questionnaire may provide sport and performance coaches with an improved understanding of the individual response to practice and competition, and contribute to the design of training and recovery protocols to enhance subsequent competitive performance.  The ease of administration and cost effectiveness associated with individual athlete monitoring via wellness questionnaires, permits football teams, at every level, to implement these strategies throughout the in-season period.

Future studies should examine how coaches seeking to enhance competitive performance, can manipulate individual and position-specific practice volumes and intensities to mitigate fatigue, enhance recovery, and optimize subsequent competitive performance.  Although it was beyond the scope of the present study, future investigations should also examine the impact of perceived wellness ratings on competitive performance and injury risk in NCAA division I football players.

### 7.5 Practical Applications

The present study provided a novel analysis of the physiological and psychological response to competitive movement demands and training loads associated with in-season weekly practice sessions.  Results support the implementation of a questionnaire consisting of four subscales, including fatigue, soreness, stress, and sleep quality.  A Likert scale with five response choices, or alternatively, having individuals compare their current well-being to normal (worse than normal, normal, better than normal) offering three response choices, similar to the DALDA (204), may be employed.  Consideration as to the number of questions and potential responses, which ease the time burden on the athlete, while simultaneously obtaining valuable data, is critically important.

Due to weekly competition associated with an NCAA football season, performance coaches should monitor individual perceived wellness on a weekly basis. Recovery modalities should be implemented for individuals reporting less than favorable ratings of fatigue and soreness one day following games. Additionally, an assessment of perceived wellness should be undertaken within 48 hours prior to subsequent competition, to examine the impact of weekly practice sessions on the well-being of college football players. Results of the present study do not support practice load reductions on Game -4 and Game -3 in attempts to improve well-being on Game -2, even for players who reported less than favorable ratings of wellness on Game +1. However, coaches should evaluate individual wellness scores prior to games, and initiate communication with athletes who report unfavorable wellness scores on Game -2. Interpersonal communication conveys a sense of concern for the player, ensuring the athlete that wellness scores are being monitored and their input is meaningful, and provides coaches increased information from which to program training loads and recovery modalities for individuals who report less than favorable wellness ratings on Game -2. Minimizing the deleterious effects of fatigue while simultaneously improving the position-specific technical, tactical, and physical demands associated with athlete preparation in division I college football players requires a collaborative effort between members of the coaching staff, medical staff, performance staff, and most importantly, the athletes themselves. The ease of administration, cost-effectiveness, and the minimal time investment required to collect perceived wellness data, makes it a practical tool for monitoring team sport athletes.

# Chapter 8

## General Discussion, Conclusions, and Future Research

### 8.1 Quantification of Competitive Game Demands of NCAA Division I College Football Players Using Global Positioning Systems

Despite the popularity of NCAA division I college football in America, there remains a lack of information regarding the physiological demands and position-specific movement characteristics associated with competition. American football is a field-based team sport requiring high levels of muscular strength, power, and speed, involving intense collisions and repeated high-intensity movements, with each position group having distinct physiologic and biomechanical demands associated with specific technical and tactical requirements. Games are intermittent in nature and involve high-intensity movements including sprinting, backpedaling, accelerating and decelerating. The quantification of team-sport competition demands using GPS technology has been reported in similar collision based team sports, however uncertainty exists regarding the position-specific movement demands of NCAA football competition.

The results of the present research indicate that significant differences in positional movement demands accompanying participation in NCAA division I football games exist. The most notable finding for physical characteristics of games in both offensive and defensive teams were the movement profiles of the WR, DB, and LB positions, with athletes in these three position groups covering more total distance at higher intensities compared to all other positions on their respective offensive and defensive teams. The present study found a significant difference in total distance traveled between position groups within both the offensive and defensive teams. The WR position group covered more total distance per game than all other offensive groups. Similarly on defense, the DB and LB position groups covered greater total distance than the DT and DE position groups. The findings of the present study demonstrating positional differences in total distance is consistent with previous research (56) that found significant differences in distance traveled between linemen and non-lineman during pre-season training camp practices.  In addition to differences in total distance covered by WR, DB, and LB, the present study demonstrated significant differences in moderate-intensity, high-intensity, and sprint distances covered by WR, DB, and LB compared to all other positions on their respective teams. The RB and TE covered significantly more high-intensity distance than OL. Similar observations in American football training were made by Demartini et. al. (56) who reported non-linemen covering significantly more high-intensity distance for position drills, team drills, and total practice time than linemen in pre-season training camp practice.

Investigations in team sports similar to American football, including Rugby League, Rugby Union, and Australian rules football, indicate significant positional differences exist in high-intensity movements including acceleration and deceleration efforts (213, 242), and maximal speed (33, 160). The present study found significant differences in maximal running speeds and maximal acceleration and deceleration efforts recorded from offensive position groups. The average maximal speed of WR position was significantly greater than all other offensive positions except QB.  The RB and QB position groups' average maximal speed was significantly greater than that of both the TE and OL position groups. The WR group had significantly more sprint, maximal acceleration, and maximal deceleration efforts than all other offensive position groups, presumably do to repeated route running requiring sprinting and frequent changes of direction.  The DB group had significantly more sprint, maximal acceleration, and maximal deceleration efforts than all other defensive positions, highlighting the specific high-intensity running requirements of this position during defensive play.  The LB position group demonstrated significantly greater average maximal speeds, sprint, maximal acceleration, and maximal deceleration efforts than the DE and DT groups.

The contribution of the current research to the understanding of the physiological movement characteristics is evident based on a lack of previous research utilizing GPS technology to evaluate the physical demands of NCAA football competition. Data presented in the current study represent the first investigation of the position-specific movement demands of NCAA division I football competition, and as such, have a high degree of novelty. The results of the present study confirm our hypothesis that significant positional differences in game-day movement demands of NCAA Division I college football players exist. Furthermore, the increased understanding of the demands of NCAA division I football competition provided by the present research is vital for identifying position-specific performance characteristics for performance coaches seeking to implement a systematic approach, which adequately prepares players for the rigors of competition.

## 8.2 Quantification of Accelerometer Derived Impacts Associated With Competitive Games in NCAA Division I College Football Players

American football is a field-based team-sport with competition characterised by repeated short-duration, high-intensity, intermittent movement patterns involving accelerations, decelerations, sprinting, and multi-directional running. Additionally, athletes are exposed to frequent collisions and blunt force trauma associated with repeated contact with opponents and the ground during tackling, blocking, and ball-carrying activities (216). The characteristics of repeated collisions and the associated blunt force trauma resulting from competition in Rugby League and Rugby Union players have been reported and significant inter-positional differences in total impacts experienced have been demonstrated during competition (156, 220). Due to the intense physical demands associated with American football competition, a quantitative examination of position-specific impact profiles may provide an increased understanding of the competitive demands for individuals participating in NCAA division I football games. Despite the widespread inclusion of GPS and IA technology in collegiate American football programs, there remains a paucity of research regarding the characteristics of collisions experienced by players during competition.

The findings of the present research indicate significant positional differences in the number and intensity of impacts associated with NCAA division I college football competition.

Specifically, the WR, DB, and LB position groups underwent more very light impacts than all other offensive and defensive position groups, which is a likely relfection of positional differences in running volumes. Previous research (235) examined movement profiles associated with competitive games in NCAA division I football players, and reported significantly greater total distance for the WR, DB and LB position groups. This supports the results of the present study, indicating the increased number of very light impacts detected in these position groups may be attributed to the increased running volumes experienced as a result of their unique positional demands. The RB position group recorded the greatest number of severe impacts throughout the course of competition, which may reflect the characteristic high-velocity collisions with defenders associated with the positional demands of being the primary offensive ball carrier. These findings are substantiated by previous descriptions of the nature of severe impacts in contact team-sport (158), which described severe impacts as being indicative of high-intensity collisions with the opponent, making a direct front-on tackle on an opponent traveling at a high velocity, or being tackled by multiple opponents while running at maximal velocity. Defensively, the physicality of the DT position was demonstrated by significantly more heavy and very heavy impacts than all other defensive position groups.

The results of current study allow the hypothesis to be accepted that NCAA division I football games result in significant positional differences in the number and intensity of impacts recorded via GPS and IA microtechnology. Additionally, the present research provides insight to positional impact profiles associated with NCAA division I football competition not previously reported, and as such, comparing the findings of the present study with the existing knowledge of positional game demands is problematic. Investigations in contact team-sport similar to American football have demonstrated interpositional differences in the quantity and intensity of impacts associated with competition, supporting the findings of the present study. Although the positional impact profiles in similar collision-based team sport have been investigated, a lack of research quantifying the impact profiles associated with college football games exists. Accordingly, the present study serves as a novel investigation quantifying position-specific impact profiles and provides scope for performance coaches seeking to enhance position-specific training strategies and recovery protocols to optimize competitive performance.

### 8.3 Movement Demands and Perceived Wellness Associated With Pre-Season Training Camp in NCAA Division I College Football Players

NCAA division I football teams participate in an intensified pre-season training camp that typically commences 4-5 weeks prior to the first competition. A lack of information exists, within the established literature, quantifying the practice demands of the pre-season period, which observationally, respresents the most intense training period of the year. Programming training loads during the pre-season practice period, which maximize positive physiological adaptations and minimize excessive fatigue that may be associated with maladaptation, may pose significant challenges to coaches and performance staff. Accordingly, the objective quantification of positional movement demands, including volume, intensity, and duration of physical activity completed, commonly referred to as external load, and the relative physiological and psychological stress imposed as a result of training, referred to as internal load (97), is appropriate. Subjective measures of perceived wellness are efficient, inexpensive, and non-invasive (150), and have demonstrated sensitivity to training stress and a dose-response relationship with training load (190) (209). In elite contact team sport, significant correlations have been reported between fluctuations in daily training load and changes in subjective ratings of wellness (27). During intensified periods of competition in sports characteristic of American football, significant changes in perceived well-being accompany performance decrements, decreases in neuromuscular power, and increases in biochemical markers of muscle damage (116). Consequently, it has been recommended that coaches and performance staff utilize brief, customized questionnaires within an athlete monitoring system (106).

The findings of the present study confirm our hypothesis that significant ($p<0.05$) differences in positional movement demands exist in NCAA division I college football players participating in pre-season football camp. Additionally, significant ($p<0.05$) differences and GPS and IA training loads in the preceding day's practice resulted in differential ratings of perceived wellness the following day. Similar to previous investigaitons in college football (235), significant differences in total distance and acceleration and deceleration distance covered by the WR, DB, and LB position groups, and in high-intensity and sprint distance covered by WR and DB compared to all other positions on their respective offensive or defensive teams, were reported.

A novel examination of perceived wellness in NCAA division I football players revealed significant ($p<0.01$) differences for every GPS and IA practice variable, except sprint distance, from the preceding day, distinguishing a perceived fatigue rating of 1 or 2 from a 3, and 3 from a 4 or 5. Significant ($p<0.001$) differences in total, low-, medium-, and high-intensity running distance and acceleration and deceleration distance at all intensities were demonstrated between individuals who rated their level of perceived soreness a 1 or 2 and those who rated it a 3, 4, or 5. Additionally, significant ($p<0.05$) differences in PL distinguished soreness ratings of 1 or 2 from a 3, and a 3 from a 4 or 5. Examinations in Australian footballers (27) have also demonstrated daily variations in external load associated with pre-season training camp have a significant ($p<0.001$) impact on wellness measures, including soreness, fatigue, sleep quality, stress levels and mood the following day, supporting the results of the present study. Significantly ($p<0.05$) less running distance and acceleration and deceleration distance at all intensities were demonstrated for individuals rating perceived sleep quantity a 4 of 5 vs. a 1, 2, or 3. Additionally, significant ($p<0.05$) differences in PL, high-intensity acceleration and deceleration distance, and max-intensity acceleration distance were able to distinguish a sleep quantity rating of a 1 or 2 from a 3 and a 3 from a 4 or 5. Individuals who responded more favorably, indicated by a rating of a 4 or 5 for the subscale of perceived stress, demonstrated significantly ($p<0.05$) less PL, total, low-, medium-, and high-intensity running distance and acceleration and deceleration distance at all intensities, in the preceding practice session than those who rated perceived stress a 3.

The present study demonstrated significant differences in the positional movement demands of division I football players participating in pre-season camp, highlighting the importance of position-specific training programs to adequately address the physical demands associated with this period of training. In addition, the present study was the first to investigate the perceived wellness of NCAA division I football players participating pre-season training camp practices. Significant differences in volumes and intensities of GPS and IA movement variables were reported in athletes who responded more or less favorably on perceived wellness subscales. The use of wellness questionnaires may provide sport coaches and performance managers an increased understanding of the training response associated with pre-season training camp practice loads, and provide increased certainty when programming and adjusting the individual training load prescriptions in pre-season training camp.

### 8.4 A Comparison of Pre-Season and In-Season Practice and Game Loads in NCAA Division I Football Players

Following quantifications of the position-specific movement demands and impact profiles associated with in-season competition in studies 1 and 2, and the pre-season movement demands and subsequent perceived wellness in study 3, the present study compared the IA-derived player loads encountered in pre-season practice with those experienced throughout the in-season competitive period in NCAA division I football players. Pre-season training camp traditionally involves loads that are programmed to maximize positive physical adaptation and minimize maladaptation that may be associated with acute and cumulative fatigue. While Study 3 quantified the position-specific movement demands associated with pre-season practice, data comparing pre-season loads to those encountered throughout the in-season period are nonexistent.

The results of the present study confirm our hypothesis that significant differences in training loads associated with pre-season training camp, when compared to the in-season competitive period in NCAA division I football players, exist. The most notable findings were the significantly ($p<0.05$) greater PLMax values attributed to pre-season week 1 compared to PL resulting from all in-season practices, and the significantly ($p<0.05$) higher cumulative PL reported for pre-season weeks 1, 2, and 3 compared to the cumulative PL for every in-season week.  In the present study, week 1 of pre-season practice resulted in significantly ($P<0.05$) higher PLMax and PLMean values than both weeks 2 and 3 of pre-season.  The PLMax achieved in the first week of pre-season camp was significantly ($p<0.05$) higher than the PL resulting from 42% of games, and all Game -4, Game -3, and Game -2 practice sessions throughout the in-season period.  The PLMean resulting from pre-season week 1 was significantly ($p<0.05$) higher than PL values of all Game -3 and Game -2 practices, nine of twelve Game -4 practice sessions, and two games.  These novel data clearly demonstrate that week 1 of pre-season exposed players to the highest PL of the pre-season and in-season practice period, in addition to significantly ($p<0.05$) higher PL than 5 out of 12 games. Only one game was associated with a significantly ($p<0.05$) higher PL than the PLMax achieved in pre-season week 1.  A comparison of these reults with previous investigations in NCAA division I football is problematic, however increased training loads and session durations in the pre-season period, when compared to the in-season competitive period, has been reported in similar collision-based team sport (170) (195).

During the in-season period, the Game -4 practice sessions were planned as the highest practice loads of the week, and PL resulting from in-season Game -4 practices were significantly ($p<0.05$) greater than PLMean in pre-season week 2 for weeks 2 – 8 during the in-season period.  The PL associated with the Game -4 practice session for in-season week 1 was significantly ($p<0.05$) lower than the PLMean in pre-seasonweek 2, the likely result of a reduction in session duration in attempt to mitigate any deleterious effects of fatigue accumulated in pre-season training camp.  A similar pattern was demonstrated for Game -3 practice sessions whereby in-season week 1, 10, 11, and 12 demonstrated significantly ($p<0.05$) lower PL than the PLMean reported in pre-season week 2.  An examination of the cumulative weekly PL revealed significantly ($p<0.05$) greater cumulative PL for pre-season week 1 than weeks 2 and 3 of pre-season, and significantly ($p<0.05$) greater cumulative PL for pre-season week 2 than pre-season week 3.

The present study demonstrated significantly ($p<0.05$) higher workloads in pre-season1 than any other phase of pre-season camp, and although the optimal pre-season practice session training load required to produce favorable physical adaptations and mitigate undesirable consequences associated with excessive fatigue has not been established, improvements in load programming may prove advantageous. The PLMax achieved in pre-season week 1 in the present investigation, is comparable to the PL which may be experienced by NCAA division I football players during competition. Collectively, these data contrast training load progression recommendations provided to mitigate injury risk (110) and optimize athlete preparation prior to the commencement of the NCAA division I football season. Accordingly, it is reasonable to question the appropriateness of this particular loading scheme for week 1 of pre-season training camp, particularly in light of previous research demonstrating increased risk of injury and illness associated with acute spikes in training load (110) (184). Data from the present study augment our understanding of the practice demands experienced by NCAA division I college football players, and provide scope for the improvement of pre-season practice design and physical conditioning strategies for coaches seeking to optimize competitive performance.

### 8.5 Perceived Wellness Associated With Practice and Competition in NCAA Division I Football Players

The use of data obtained via questionnaires to evaluate the perceived wellness associated with GPS and IA-derived movement demands in pre-season camp, as outlined in chapter 5, represents a novel approach to investigating the physical demands and corresponding psychological response of NCAA division I football players to pre-season training camp. The judicious monitoring of the individual psychological response to exercise loads encountered in practice and competition is vital for maximizing competitive performance. Currently, the impact of GPS-derived movement variables associated with practice and game demands on perceived wellness during the in-season competitive period remain ambiguous. A more comprehensive understanding of the perceived psychological response to the game-day movement demands will provide performance staff a model from which to plan post-game recovery modalities and program subsequent training sessions. Further, evaluating the impact of weekly in-season, Game -4 and Game -3, practice loads on Game -2 perceived wellness, will provide novel insight for coaches seeking to manage the deleterious effects of fatigue and optimize subsequent game-day performance.

The results of the current study confirm our hypothesis that differences in perceived wellness were associated with significant differences in individual movement characteristics attributed to practice and competition. Individuals who accrued significantly ($p<0.05$) less PL, running distance at all intensities, and deceleration and acceleration distance at all intensities during NCAA division I football games, reported more favorable ratings of perceived fatigue the day following the games. Similar findings with respect to perceived soreness the day following games were demonstrated by significantly ($p<0.05$) less PL, running distance at all intensities, except for sprint distance, and acceleration and deceleration at all intensities in individuals who reported more favorable ratings. Conversely, players who reported more favorable perceived stress responses the day following games demonstrated significantly ($p<0.05$) greater movement demands associated with competition than those who rated perceived stress less favorably. The results of the present study suggest that increased game-day movement demands may be directly associated with a less favorable perceived fatigue and soreness response, but a more favorable perceived stress response the day following games.

A previous investigation (72) in NCAA division I demonstrated less favorable ratings of perceived soreness and overall wellness persisting for up to four days following competition, however the perceived wellness the day following competition was not evaluated, and the GPS-derived movement demands associated with wellness responses were not investigated. Similar findings of increased perceived soreness and fatigue one day following contact team-sport competition have been demonstrated by researchers (153) (230) who utilized a questionnaire similar to the one in the present study, and reported significant ($p<0.01$) increases in fatigue and soreness ratings one day following Rugby League match-play, when compared to pre-match values. The scope of these studies, however, did not include the utilization of microtechnology to assess competitive movement demands to determine which

GPS-derived movement variables may influence the differential ratings of perceived wellness the following day.

In the present study, several GPS-derived variables were able to differentiate individuals whose rating of perceptual stress was a 4 or 5 vs. a 1 or 2, and those who rated stress a 3 vs. a 1 or 2. Data indicated more favorable perceived stress responses with increases in game-day exercise demands. These findings are in agreement with the results reported by Hartwig et. al. (100) which demonstrated an inverse relationship between training volumes and perceptual stress ratings in Rugby Union players during the in-season period. These data may indicate an inverse relationship between the perceptual stress response and movement demands associated with competitive game in NCAA division I athletes, perhaps due to psychological factors unaccounted for, including self-satisfaction (100).

Significant unidirectional relationships were demonstrated between the GPS-derived movement demands of competition and perceived fatigue on Game +1, however similar significant unidirectional relationships were not established when examining the impact of Game -4 and Game -3 practice sessions on Game -2 perceived fatigue. Individuals who accumulated significantly ($p<0.05$) greater medium-intensity and high-intensity deceleration and medium-intensity and maximal-intensity acceleration distance on Game -4 and Game -3 practice sessions experienced an improvements, indicated by higher scores, in perceived fatigue on Game -2. These improvements were seen in individuals who rated perceived fatigue a 1 or 2 on Game +1 and improved to a 3 on Game -2, and those who were a 1, 2 or 3 on Game +1 and improved to a 4 or 5 on Game -2, when compared to individuals who rated perceived fatigue a 4 or 5 on both Game +1 and Game -2. The results of Game -2 assessments of perceived fatigue in the present study are supported by previous research (100) in Rugby Union players which demonstrated more favorable recovery scores in players who had the highest training and physical activity volumes during the in-season period. Data from the present study suggest that individuals with more unfavorable, or lower, ratings of perceived fatigue on Game +1 are not hindered by increased practice loads on Game -4 and

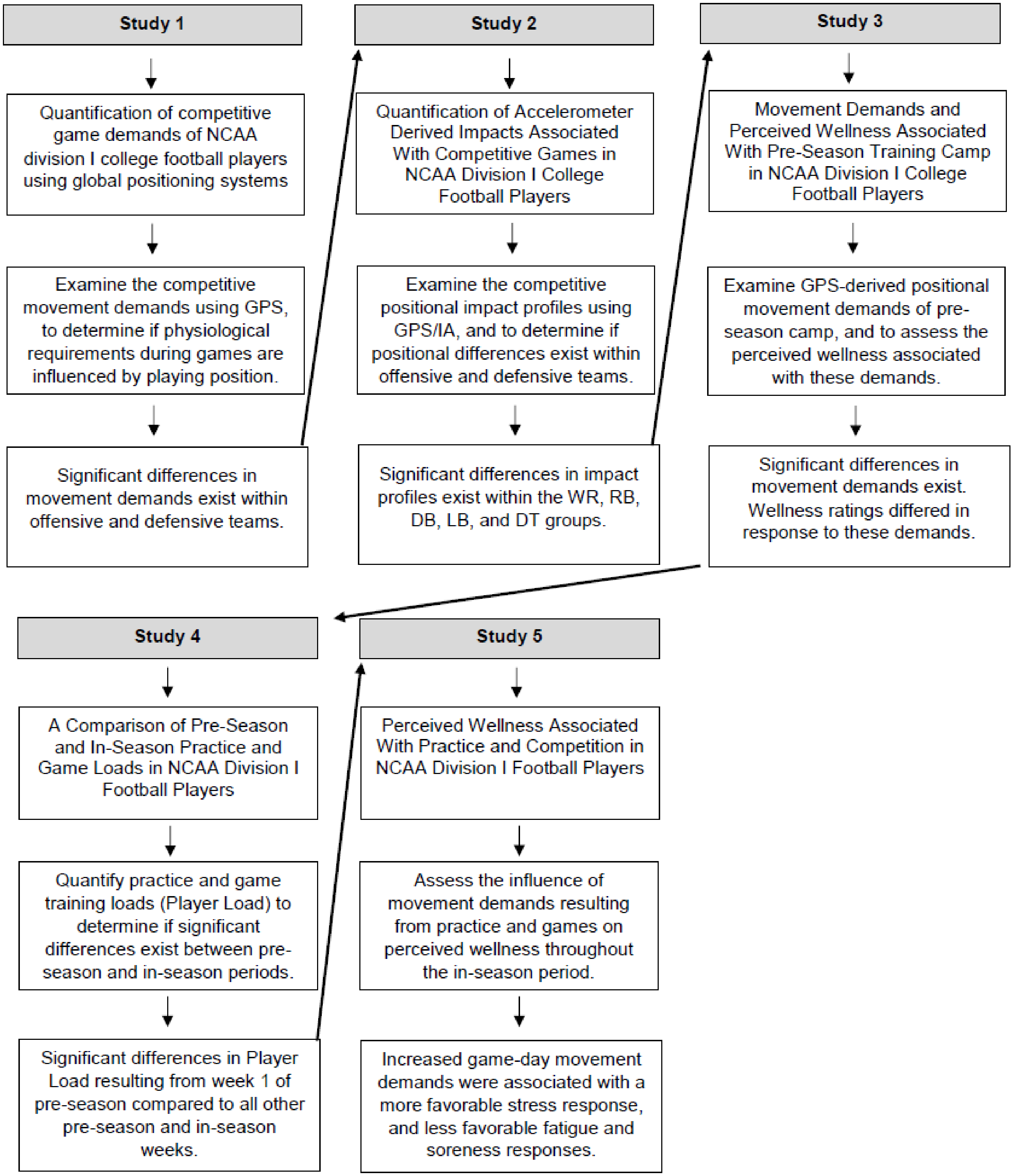
Game -3, but may actually experience improvements in perceived fatigue ratings on Game -2.

A lack of unidirectional findings of Game -2 perceived wellness was also demonstrated for the subscales of perceived soreness and stress. Individuals who rated perceived soreness a 4 or 5 on both Game +1 and Game -2 accumulated significantly ($p<0.05$) greater PL, high-intensity deceleration distance and maximal-acceleration distance in Game -4 and Game -3 practice sessions than those whose soreness rating improved from Game +1 to Game -2, and those whose rating was the same or became worse from Game +1 to Game -2.

It is unclear whether differences in practice loads in the present study were responsible for improvements demonstrated in some wellness subscales, or if other factors including days until competition (83) and under-reporting unfavorable responses (63) in attempt to appear better, or more well adjusted, played a role.

The results of the present study contribute novel insight into the perceived wellness associated with practice and competitive loads experienced by NCAA division I college football players throughout in-season period and the implementation of wellness questionnaires within an applied, high-performance setting. Data from the present study provide an increased understanding of the impact of specific game-day movement variables on post-game perceptual wellness, and support the implementation of a perceived wellness questionnaire to quantify perceptual recovery following NCAA division I football games.

## 8.6 Schematic Summarizing Studies 1-5



### 8.7 Recommendations for Future Research

The present research provides novel insight into the position-specific movement demands of pre-season and in-season practice and competition, and the perceived wellness associated with these specifc demands in NCAA division I football players. To further increase our understanding of the demands of NCAA division I football participation, the time-course of recovery, and the readiness for subsequent performance, the following directions for future research may prove beneficial.

1. To improve our understanding of the physical demands NCAA division I football competition, a more comprehensive analysis of game demands across several teams would bolster the established data, and provide increased scope for coaches to further define position-specific performance and improve athlete preparation.

2. The number of physical collisions and high-velocity changes of direction associated with impact profiles in NCAA division I football players may potentially effect recovery following competition. An investigation of relationship between position-specific impact profiles, muscle damage, and neuromuscular fatigue may provide a more comprehensive analysis of NCAA division I football competition.

3. To compliment the present research, an examination of the relationship of neuromuscular fatigue with ratings of perceived wellness in pre-season training camp, may provide coaches and performance managers greater insight for practice planning to mitigate excessive fatigue and improve subsequent performance.

4. When comparing exercise loads from pre-season training camp to those encountered during in-season practice and competition, a more comprehensive analysis of several NCAA division I football teams may improve our understanding, and ultimately, may catalyze a philosophical shift among coaches who repeatedly prescribe higher training loads at the commencement of pre-season camp.

5. Following completion of the present research, subsequent investigations seeking to establish relationships between GPS-derived movement variables, perceived

wellness, and injury incidence throughout the course of a season may be of considerable interest to sport coaches and performance managers.

**Appendix A**

**Explanatory Statement**

**Bond University BUHREC Protocol Number: RO-1929**

Chief Investigator: Dr Chris McLellan

Chief Investigator: Dr Grant Goulet

Co-Investigator: Mr Aaron Wellman

**Project title:** Quantification of performance characteristics in national collegiate athletic association division one football using global position systems.

**University of Michigan Athletics Department**

**Sports Administration**

**Purpose:**

The aim of the proposed study is to quantify performance characteristics of national collegiate athletic association (NCAA) division one football using global positioning system (GPS) and integrated accelerometry (IA), throughout the course of 2014 – 2015 off-season and in-season practice and match-play.

**Your involvement in the project:**

You will be asked to grant acces to the GPS datasets that has or will be collected from the 2014 / 2015 NCAA division one football seasons. Given GPS data is currently being collected by the University of Michigan athletics department for athlete monitoring, your involvment in the proposed study is to provide data to researchers for statistical analysis of trends and detailed quantification of physical demands. Researchers hope that by statistically analysing GPS data from training and compeition, they can accurately quantify the physical demands of NCAA division one football practice and match-play, which may subsequently improve athlete monitoring programs. Researchers will contact the University of Michigan athletics department and arrange to dicuss any concerns you may have about the research project, and at this time you will be taken through the planned analysis of the GPS datasets you provide (outlined below). Further, at this meeting you will be asked to provide consent for researchers to access your GPS database at the appropriate time. Once data has been arranged correctly (outlined below) the database will be transferred from the University of Michigan athletics department to researchers via USB. All data provided will need to be de-indentified, meaning no athlete names can be attached to GPS information provided to researchers, with the only personal information required from the athlete being playing position for analysis purposes (further outlined below).

**Your rights:**

You may withdraw your consent to provide data to researchers freely and without prejudice at any time. If at any time you choose to withdraw your consent to provide GPS data, the database provided will be deleted and excluded from the study.

**What are the risks and benefits of participating:**

There are no health and well-being risks of participation. All information you provided must be de-identified, as such there is no risk of individual's information becoming public knowledge. Further, all data will be presented in grouped format.

Participation is beneficial to the University of Michigan athletics department and athletes participating in NCAA division one football, as it will provide information which will help identify trends in exercise loads and physical demands of competition and practice.

Subsequently, researchers may identify information which may enhance practice modalities and recovery strategies to optimize athlete performance and monitoring. Information will also provide defined parameters about the physical requirements of participation in NCAA division one football.

**Confidentiality:**

Steps have been taken to ensure the confidentiality of all data at all times. The database provided will be held on USB by the investigators. Data will be stored on a secure password protected computer within Bond University. Upon completion of the research study, you will be provided with the results and a conclusion report by researchers. The identities of each GPS dataset will not be requested or should not be provided to researchers, and as such, no individuals will be identified in any subsequent research presentations or reports. All data will be presented in group format.

**GPS database requirements:**

In order to manage the GPS data analysis effectively and ensure safety and security of identities for all participants from whom the data was collected, researchers require the following from the University of Michigan athletics department.

- All datasets to ONLY contain the following variables.
- Athlete playing position, date of data collection, total distance, low intensity distance, high intensity distance, sprint distance, max speed, sprint count, moderate, high and max intensity accelerations and decelerations, moderate and heavy impacts, collisions and body load.
- Please do not add any additional information to the GPS datasets and please enter the data into the excel spreadsheet in its provided format.

If you choose to participate in this research project, you will be provided with an excel spreadsheet template to enter the GPS datasets into – please see the final page "example" of what the database will look like.

Once you have competed the addition of all relevant GPS datasets to the database, you will be asked to contact the researchers and set up a data exchange meeting.  At this time, prior to collection of data, researchers will check the format of the database to ensure it follows all guidelines. Researchers will transfer data to a secure password protected computer for subsequent statistical analysis.

**Additional information regarding research:**

The use of global positioning systems (GPS) and integrated accelerometry (IA) in team-sports has had a profound impact on sports science over the past decade, allowing for the quantification and monitoring of physical loads undertaken by athletes during field-based practice and match performances. Global position system technology allows for the quantification of movements and forces during training and matches, is considered accurate for team-sports use, and provides insight into physical performance variables such as, distances, velocities, accelerations, decelerations and collisions.

Despite the rapid expansion of research using GPS IA in field-based team-sports, there is limited research which has quantified performance characteristics of National Collegiate Athletic Association (NCAA) division one football. Quantification of key performance characteristics in other sports similar to NCAA division one football, such as professional Rugby League and Rugby Union, has helped sports scientists and strength and conditioning coaches augment practice and recovery strategies to optimise athlete well-being and performance. As such, quantification of match-play and training in NCAA division one football may help to improve the preparation of athletes for matches, and aid in improving athlete well-being by reducing injuries and fatigue caused by an imbalance of practice and recovery.

The aim of the purposed study is to examine performance characteristics of NCAA football using GPS IA technology throughout the course of off-season and in-season training and match-play.

If you have any queries please contact:

Dr Chris McLellan
cmclella@bond.edu.au
Dr Grant Goulet
gcgoulet@umich.edu
OR
Mr Aaron Wellman
Phone: (734) 276 – 5417
Aaron.wellman@student.bond.edu.au

Should you have any complaint concerning the manner in which this research is conducted, please do not hesitate to contact Bond University Research Ethics Committee, quoting the Project Number (above):

The Research Ethics Manager Office of Research Services

Building 1C Level 4

Bond University, QLD 4229.

Telephone (07) 5595 4194 Fax (07) 5595 1120

Email: buhrec@bond.edu.au

**Appendix B**

**University of Michigan**

**Consent to be Part of a Research Study**

**Information about this form:**

You may be eligible to take part in a research study. This form gives you important information about the study. It describes the purpose of the study, and the risks and benefits of participating in the study.

Please take time to review this information carefully. After you have finished, you should talk to the researchers about the study and ask them any questions you have. You may also wish to talk to others (for example, your friends, family, or physicians) about your participation in this study. If you decide to take part in the study, you will be asked to sign this form. Before you sign this form, be sure you understand what the study involves, including the risks and possible benefits to you.

**General information about this study and the researchers:**

**Study title: Quantification of performance characteristic in national collegiate athletics association division one football using Global Positioning Systems.**

**Names, degrees, and affiliations of he researchers conducting the study:**

Chris McLellan, Ph.D – Faculty of Health Science and Medicine, Bond University

Sam Coad – Faculty of Health Science and Medicine, Bond University

Aaron Wellman – Faculty of Health Science and Medicine, Bond University

Grant Goulet, Ph.D. – School of Kinesiology, University of Michigan

**Invitation to participate in a research study:**

The above-named researchers invite you to participate in a research study that aims quantify performance characteristics in NCAA Division one football training and match-play using novel global positioning systems technology. The use of global positioning systems (GPS) and integrated accelerometry (IA) in team-sports has had a profound impact on sports science over the past decade allowing for the quantification and monitoring of physical loads undertaken by athletes during field-based practice and match performances. Global position systems technology allows for the quantification of movements and forces during training and matches, is considered accurate for team-sports use, and provides insight into physical performances variables such as, distances, velocities, accelerations, decelerations and collisions. Despite the rapid expansion of research using GPS IA in field-based team-sports, there is limited research which has quantified performance characteristics of National Collegiate Athletic Association (NCAA) division I football. Quantification of key performance characteristics in other sports similar to NCAA division I football, such as professional Rugby League and Rugby Union, has helped sports scientists and strength and conditioning coaches augment practice and recovery strategies to optimize athlete well-being and performance. As such, quantification of match-play and training in NCAA division I football may help to improve the preparation of athlete for matches, and aid in improving athlete well-being by reducing injuries and fatigue caused by an imbalance of practice and recovery. The aim of the purposed study is to examine performance characteristics of NCAA football using GPS and IA technology, throughout the course of off-season and in-season training and match-play.

**Description of the human subject involvement:**

Participants in the present study are wearing global positioning systems for the primary reason of performance analysis by the University of Michigan Football Program. There will be no human subject involvement between the researchers and the participants. Information collected by the University of Michigan football team will be databased and provided to the researcher at the conclusion of the 2014 / 2015 seasons with the consent of the Director of Football Operations for University of Michigan Football.

**Benefits:**

By providing researchers with Global Positioning Systems (GPS) data different performances trends in NCAA football athlete may help physical performance staff augment training and recovery strategies. Further, the quantification of training and matches using GPS may help coaches improve training modalities to subsequently improve athlete performance and decrease incidences of athlete injury / fatigue.

**Risks and discomforts of participation:**

- Since you are performing demanding lower-limb movements, there is the possibility that you may suffer some form of joint or muscle injury during the study. Considering your age and current fitness level, such responses are unlikely. You will be given ample time for warm-up and stretching.
- There is also the potential risk of loss of confidentiality through participation in this study. Every effort will be made to keep your information confidential; however, this cannot be guaranteed.
- As with any research study, there may be unanticipated risks.
- Please consider the risks of participation carefully.

**Compensation:**

You will not be offered any compensation for your participation in this study.

**Confidentiality:**

We plan to publish the results of this study, but will not include any information that would identify your athletes. There are some reasons why people other than the researchers may need to see information you provided as part of the study. This includes organizations responsible for making sure the research is done safely and properly, including the University of Michigan and government offices.

The identity of athletes in your program safe, the researchers will not be able to access names fo participants. The database provided to researchers will be password-protected and stored on a secure server. Researchers, other than those listed on this study, will not have access to the database. While the study is ongoing, we will have a file that links your study number with your name, which will be password protected and stored on a secure server.

**Storage and future use of data:**

The data you provide will be stored on a secure server. All files will be password protected. The researchers will retain the data indefinitely. The data will not be made available to other researchers for other studies following the completion of this research study and will not contain information that could identify you.

**Voluntary nature of this study:**

Participating in this study is completely voluntary. Even if you decide to participate now, you may change your mind and request that you stop at any time. If you decide to withdraw early, we will utilize the data that we had collected prior to your withdrawal.

**Contact information:**

If you have questions about this research, you may contact:

Grant C. Goulet, PhD
Director, Human Performance Innovation Lab

School of Kinesiology, University of Michigan
Phone: (734) 780-7098
Email: gcgoulet@umich.edu

If you have questions about your rights as a research participant, or wish to obtain information, ask questions or discuss any concerns about this study with someone other than the researcher(s), please contact the University of Michigan Health Sciences and Behavioral Sciences Institutional Review Board. Contact information: 540 E. Liberty St., Suite 202, Ann Arbor, MI 48104-2210; (734) 936-0933 [or toll free, (866) 936-0933]; irbhsbs@umich.edu.

**Consent of the subject:**

By signing this document, you are agreeing to participate in this study. You will be given a copy of this document for your records and one copy will be kept with the study records. Be sure that questions you have about the study have been answered and that you understand what you are being asked to do. You may contact the researcher if you think of a question later.

*I agree to participate in this study.*

______________________________________

Name

______________________________________ ____________________

Signature Date

## Appendix C

### Explanatory Statement

**Project Title:** Quantification of performance characteristics in National Collegiate Athletic Association Division I football using global positioning systems

**Principal Investigators:**

- Aaron Wellman (Department of Athletics, University of Notre Dame)
- Chris McLellan (Faculty of Health Sciences and Medicine, Bond University)
- Patrick Flynn (Department of Computer Science and Engineering, University of Notre Dame)

**General Purpose of Study:** The aim of the proposed study is to quantify performance characteristics of national collegiate athletic association (NCAA) division I football using global positioning system (GPS) and integrated accelerometry (IA), throughout the course of 2015 – 2016 off-season and in-season practice and match-play.

**Your Involvement in the project:** You will be asked to grant access to the following two data sets that have been or will be collected from the 2015-2016 NCAA division one football season: (i) GPS data; (ii) fatigue questionnaire. Since these data are currently being collected by the University of Notre Dame Athletics Department for athlete monitoring, your involvement in the proposed study is to authorize the additional release of this data to researchers for statistical analysis of trends and detailed quantification of physical demands. Researchers hope that by statistically analyzing GPS and questionnaire data from training and competition, they can accurately quantify the physical demands of NCAA division one football practice and match-play, which may subsequently improve athlete monitoring programs. Research team members are available to discuss any concerns you may have about the research project, and at this time you will be taken through the planned analysis of the GPS and questionnaire datasets you provide (outlined below). You will be asked to provide consent for researchers to access your GPS and questionnaire database at the appropriate time. Once data has been reformatted as described below, the database will be transferred from the University of Notre Dame Athletics Department to the research team as electronic documents. All data provided will be de-identified, meaning no athlete names can be attached to GPS or questionnaire information provided to researchers, with the only personal information required from the athlete being playing position for analysis purposes.

**Data to be Collected:** Athlete playing position, date of data collection, total distance, low intensity distance, high intensity distance, sprint distance, max speed, sprint count, moderate, high and max intensity accelerations and decelerations, moderate and heavy impacts, collisions, body load, and self-assessment of fatigue, sleep quality, soreness, stress, mood, and sleep duration.

**Your rights:** You may decline participation before the start of the project, or withdraw your consent to provide data to researchers freely and without prejudice at any later time prior to the end of the project. If at any time you choose to withdraw your consent to provide GPS and questionnaire data, the database provided will be deleted and excluded from the study. Declining to participate, or revoking participation at a later date will have no effect of any kind on your relationship with the University of Notre Dame.

**Confidentiality:** Steps have been taken to ensure the confidentiality of all data at all times. The database provided will be held in electronic format on password-protected computers by the Notre Dame investigators. Data will also be stored on a secure password protected computer within Bond University. Upon completion of the research study, you may be provided with the results and a conclusion report by the researchers. The identities of athletes will not be available to researchers, and as such, no individuals will be identified in any subsequent research presentations or reports.  All data will be presented in group format.

**Risks and Benefits:** There are no additional health and well-being risks of participation in this research study. All data collected from you during practice and competition is de-identified, as such there is no risk of individual's information becoming public knowledge. Further, all data will be presented in grouped format.

There is no direct benefit of this research to you as a participant. Participation is beneficial to the University of Notre Dame Athletics Department and athletes participating in NCAA division one football, as it will provide information which will help identify trends in exercise loads and physical demands of competition and practice. Subsequently, researchers may identify information that can enhance practice modalities and recovery strategies to optimize athlete performance and monitoring. Information will also provide defined parameters about the physical requirements of participation in NCAA division one football.

**Eligibility**: You must be 18 years old or older to participate in this project.

**Appendix D**

**INFORMED CONSENT**

**Project Title:** Quantification of performance characteristics in National Collegiate Athletic Association Division One football using global positioning systems

**Eligibility**: You must be 18 years old or older to participate in this project.

**Questions concerning this study:**

If you have any questions or concerns, please contact:

- Dr Chris McLellan; cmclella@bond.edu.au
- Mr Aaron Wellman; phone: (734) 276 – 5417; aaron.wellman@student.bond.edu.au
- Dr. Patrick Flynn; flynn@nd.edu; Phone: (574) 631-8803

If you have any concerns about the study, you may also contact the Office of Research Compliance at compliance@nd.edu; phone: 574-631-1389

**Consent:**

1. I have read the subject information sheet for this research project and clearly understand the content, and what is being asked of me.
2. I am 18 years of age or older.
3. Any risks associated with my participation in the project have been clearly explained to me and I clearly understand the risks involved in my participation.
4. I have had the opportunity to ask questions about the project, and the questions I have asked have been answered to my satisfaction. I also understand that I can ask questions about the project and my participation in the projects at any time.
5. I understand that my records will be handled in a confidential manner and that any reporting of results will be anonymous and aggregated.
6. I understand that I can withdraw from the project at any time without penalty of any kind, and that such withdrawal will not affect my status as a student of the University of Notre Dame or my membership on the football team in any way.
7. I understand that at the appropriate time I may receive feedback on data provided for the project.
8. I understand that the project will be carried out as described in the information statement, a copy of which I have retained.
9. I give my consent to participate in the project.

Printed name of subject: ________________________________

Signatures:

Subject: ______________________________ Date: _______________________

Investigator: ______________________________ Date: _______________________

Witness: _________________________________ Date: _______________________

## Appendix E

### Wellness Questionnaire

| Category | 5 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|
| **Fatigue** | Very Fresh | Fresh | Normal | More Tired Than Normal | Always Tired |
| **Sleep Quality** | Very Restful | Good | Difficulty Falling Asleep | Restless Sleep | Cannot Sleep |
| **General Soreness** | Feeling Great | Feeling Good | Normal | Increase in Soreness / Tightness | Very Sore |
| **Stress Levels** | Very Relaxed | Relaxed | Normal | Feeling Stressed | Very Stressed |
| **Mood** | Very Positive Mood | Generally Good Mood | Less Interested in Others / Activities than Normal | Aggravated / Short Tempered | Very Annoyed / Irritable |
| **How Many Hours Did You Sleep?** (Sleep Quantity) | More Than 10 Hrs. | 8-10 Hrs. | 6-8 Hrs. | 4-6 Hrs. | Less than 4 Hrs. |

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